A GUIDE TO USING HAZUS FOR MITIGATION

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Prepared by

The National Institute of Building Sciences

For

The Federal Emergency Management Agency

Contents

Why This Guide Was Developed

A Guide to Using HAZUS for Mitigation (hereinafter referred to as the *Guide*) describes how HAZUS can help your local community, county, region or state identify, develop and implement measures to accomplish effective earthquake hazard risk reduction. The *Guide* will assist you in using HAZUS to ask questions about your community's vulnerability to earthquake damage and how such losses might be reduced by implementing preventive (mitigative) actions. It will help you understand how to use HAZUS loss estimates to develop and implement an effective community mitigation plan.

The Federal Emergency Management Agency (FEMA) defines mitigation as "sustained action taken to reduce or eliminate long-term risk to people and property from hazards and their effects." One of FEMA's principal objectives in promoting HAZUS is to encourage users to analyze, in advance, potential estimates of deaths, injuries, building damage and economic loss, and disruption to lifelines and critical facilities due to earthquakes (other natural hazards will be addressed in future versions of HAZUS), and then to design and implement measures to reduce expected losses.

Mitigation measures such as incorporating seismic design requirements into new buildings, or accomplishing seismic rehabilitation of existing buildings, will reduce the expected losses but not totally eliminate them. Improvement gained from a mitigation measure is the difference between the original condition and the improved (mitigated) condition.

Nevertheless, there are several values to be achieved when state and local governments, the private sector, public utilities, and others invest in earthquake risk reduction as part of their ongoing efforts to ensure the continuity and survivability (i.e., disaster resistance) of their respective physical assets. Besides reduced human losses and reduced physical losses from damage to the built environment, mitigation:

- Saves money by increasing the resistance of communities to earthquakes.
- When earthquakes do occur, serves to reduce community disruption; lowers response costs; lessens demands on emergency response organizations for search and rescue, fire suppression, emergency medical services, and emergency sheltering and feeding and temporary housing; and reduces the need for potentially massive assistance.
- Reduces short-term and long-term recovery costs and indirect economic impacts on the local and regional economies, such as business interruption, unemployment and business closures.

Overview of the Guide

To assist you in using HAZUS for mitigation, this *Guide* contains two sections: **Using HAZUS for the Analysis of Earthquake Risk Reduction Measures**, and **Community Mitigation Planning - The 10 Steps to Preparing a Successful Plan**.

The first section, **Using HAZUS for the Analysis of Earthquake Risk Reduction Measures**, suggests risk reduction measures and general information on how HAZUS can assist you with testing the effectiveness of these measures.

The second section, **Community Mitigation Planning - The 10 Steps to Preparing a Successful Plan**, offers a model for developing a community earthquake risk reduction plan. This process is based on the flood hazard risk reduction planning process associated with the Federal Insurance Administration's Community Rating System.

HAZUS Software Defined

HAZUS is a standardized software program that estimates losses from potential earthquakes. It is a CD-ROM-based product that requires the use of GIS (geographic information system) software to operate. HAZUS, which stands for Hazards, U.S., contains a methodology that uses mathematical formulas and information about building stock, geology, and the location and size of potential earthquakes as well as economic data and other information to produce loss estimation results. HAZUS includes databases containing the best available nationwide information on building stock, essential facilities, high potential loss facilities, population and the regional economy for all areas of the U.S. (and territories). HAZUS also provides the user with information about techniques for obtaining more accurate local data so that loss estimates can be tailored to your geographic area.

In addition to the national data provided with HAZUS, supplemental data is available on separate CD-ROMs for each U.S. state. This information can be used to assess exposure to wind and flood hazards, as well as helping communities direct response resources to their most disaster-vulnerable areas. HAZUS flood and hurricane loss estimation methodologies, analogous to the existing earthquake methodology, are being developed.

HAZUS produces easy-to-understand analytical reports and full-color maps. These products allow communities to anticipate the possible nature and scope of disaster-related damages. They can also be used to identify vulnerable areas that may require special land use or building code requirements and to assess the vulnerability of housing and essential facilities. This loss information can also be used to determine mitigation needs and to set priorities for the adoption and implementation of disaster prevention measures. A users' manual and a technical manual are available on the Internet at www.fema.gov.

This *Guide* has been written for the community planner and community Geographic Information Systems (GIS) specialist as the principal HAZUS users. The skills or knowledge needed by each to utilize HAZUS depends largely on what level of analyses will be conducted. To provide flexibility, HAZUS estimates earthquake losses at three levels:

Level 1: A rough estimate based solely on data from national databases included in the HAZUS software.

Level 2: A more accurate estimate based on professional judgment and detailed information on local geology, buildings in the community or lifelines input into HAZUS.

Level 3: The most accurate estimate based on detailed engineering and geotechnical input into HAZUS to customize the methodology to the specific conditions of the community.

For all readers, the *Guide* assumes familiarity with HAZUS. To learn more about HAZUS, a basic HAZUS training course is offered, through FEMA, at the campus of the National Emergency Training Center and the Emergency Training Institute in Emmitsburg, MD. For further information on this training, you can contact FEMA at www.fema.gov.

HAZUS – Levels of Analysis

To provide flexibility, users can estimate earthquake losses with HAZUS at three levels.

Analysis Using HAZUS-Supplied Data

Level 1 - Define a study region and choose a scenario earthquake

Analysis With User-Supplied Data

Level 2 - Add a soils map (this addition, sometimes called Level 1A, is so valuable that it should be made if at all possible).

Adjust existing data and parameters in HAZUS using local judgment or partial data.

Import data. In rough order of value and increased effort, these are:
- Improved inventory of highway bridges
- Detailed inventory of buildings or critical facilities
- Detailed inventory for other lifelines and transportation systems

Employ specific modules within HAZUS to:
- Analyze water distribution systems
- Estimate indirect economic effects

Level 3 - Import results from software run independently from HAZUS. Examples include:
- Analysis of interruption of highway system or other lifeline systems
- Flooding from dam breakage or tsunamis

Principal HAZUS Users' Required Knowledge & Skills

To use HAZUS effectively for community mitigation planning, the following knowledge and skills will be needed by planners and GIS specialists.

For the Planner

Knowledge of past, current, and future land uses and the evolution and future development of the community are essential to the planner. This knowledge needs to be linked to zoning, building and infrastructure inventories, economics, hazards, and risk information. The planner should be familiar with the community's spatial characteristics: special areas, such as historic districts; population changes and economic trends and other characteristics typically involving short-term, long-term and special planning processes. Much of the information normally used by planners, may be in GIS formats, which will be useful in applying HAZUS.

For the GIS Specialist

The GIS specialist should have a working knowledge of spatial data operations in MapInfo or ArcView GIS programs. The ability to work with dBase or similar programs is useful for inputting data into HAZUS. If HAZUS maps are to be combined digitally with other local data, such as street grids and parcels, knowledge of map scale coordination, the implications of risk mapping and disclosure, legal issues associated with digital maps, and similar subjects is required.

Basic Computer Skills Required to Use HAZUS

All HAZUS users, as a minimum, should be:

Accustomed to working in a Windows environment,

Knowledgeable of either MapInfo or ArcView, the GIS platforms HAZUS operates on,

Familiar with the general capabilities and limitations of software modeling, and

Capable of understanding and utilizing concepts of accuracy, error, scale, incremental improvements, data collection, validation and similar subjects.

Using HAZUS for The Analysis of Earthquake Risk Reduction Measures

Introduction

General Principles

The principal mitigation measures available to communities to successfully manage risk reduction are organized, for the purposes of this *Guide,* into the following categories:

- Land-Use and Geologic Hazards
- Buildings, Nonstructural Building Components and Essential Facilities
- Infrastructure: Transportation and Utilities
- Flood, Hazardous Materials and Fire Exposure

The persons involved in an analysis are likely to be land-use planners, risk managers and emergency planners. HAZUS output will consist of estimates of potential damage and loss presented in maps and tables. Examples of how HAZUS output is used in targeting and analyzing potential risk reduction measures are provided for the categories defined above in the following sections.

Using HAZUS, you can make initial, approximate loss estimates for your community, and with the assistance of the Guide, determine loss categories that may be unacceptably high and that could be significantly reduced by adopting and implementing realistic mitigation measures. The effects of various mitigation measures can then be estimated by changing certain HAZUS input characteristics that describe your community and comparing the second run's losses with the initial results. More accurate or targeted results can be obtained by improving the overall physical description of your community in HAZUS by inputting local soil maps or inventory information and then making comparative loss estimates with this improved model.

For example, Table 1 demonstrates that a 6.9 magnitude scenario earthquake is expected to cause about $1.7 billion in direct economic losses to

Table 1 - Direct Economic Losses for Buildings *(in thousands)*

	Capital Stock Losses							Income Losses		
	Cost Structural Damage	Cost Non-struct. Damage	Cost Contents Damage	Inventory Loss	Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total
Study Region Total	205,387	825,044	269,813	2,960	14.19	149,975	98,588	93,479	94,963	1,740,209

Study Region: Thirty Census Tracts in Alameda County Comprising the City of Berkeley, California

Scenario: North Hayward Fault, Magnitude 6.9

Table 2 - Casualties

	2:00 AM				2:00 PM				5:00 PM			
	At Home	At Work	Commute	Total	At Home	At Work	Commute	Total	At Home	At Work	Commute	Total
Severity 1	430	12	0	442	82	498	0	580	97	235	2	334
Severity 2	75	2	0	78	14	92	0	106	17	43	2	62
Severity 3	7	0	0	8	1	12	1	14	2	6	3	11
Severity 4	7	0	0	8	1	12	0	13	2	6	1	8
Total:	520	15	0	535	99	613	2	714	118	290	7	415

Severity 1 - Injuries requiring basic medical aid without requireing hospitalization
Severity 2 - Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life threatening status
Severity 3 - Injuries that pose an immediate life threating condition if not treated adequately and expitiously. The majority of these injuries are a result of structural collapse and subsequent collapse or impairment of the occupants.
Severity 4 - Instantaneously killed or mortally injured

Study Region: Thirty Census Tracts in Alameda County Comprising of City of Berkeley, California

Scenario: North Hayward Fault, Magnitude 6.9

Berkeley, California. About $1.3 billion will result from structural and non-structural damage to buildings, damages to building contents and furnishings, and losses of commercial inventories. Added to these capital stock losses is about another $437 million of income losses to wage earners, property owners and others.

Table 2 indicates that relatively minor injuries can be expected during the night (2:00 a.m.) when people are home (largely in wood frame dwellings, which are safer compared to other types of construction), but casualties at the two other times (2:00 p.m. and 5:00 p.m.) raise questions about building safety, particularly in office buildings and other work places during the day.

These economic and casualty loss results from HAZUS might be used as a basis to develop, enact, and enforce new building code provisions requiring earthquake resistant design of new buildings. This would at least prevent the construction of new non-earthquake resistant buildings, and leave the city in a better position to address issues associated with its existing stock of potentially earthquake hazardous buildings. Table 1 also demonstrates that non-structural losses are about four times larger than structural losses. This factor alone might trigger consideration of a combined regulatory-voluntary non-structural hazard mitigation program to reduce an earthquake's direct economic impacts. In either of these cases, the approximate reduction in losses from a mitigation measure can be estimated by changing the characteristics of the inventory to model the mitigated state, rerunning HAZUS and comparing the results with the original runs.

Table 3 - Potential Uses of HAZUS to Develop Mitigation Measures lists the types of analyses performed with

Table 3 – Potential Uses of HAZUS to Develop Mitigation Measures

Uses of HAZUS	Type of Loss Estimate	Data Requirements	Audience	Output	Comments
1. Raise public awareness of earthquake threat and consequences	Regional Scenario	Level 1 or Level 2 with soils map	General public, elected officials, emergency managers, land use planners	Casualties, economic loss	
2. Create political understanding and build constituencies	Local or Regional Scenarios	Level 2, soils map, building inventory, regional utilities or transportation systems	General public, elected officials, emergency managers, land use planners	Casualties, utility disruption, regional transportation damage dollar loss	
3. Understand relative risk, planning, siting, and access issues	Local or Regional Scenarios	Level 2, detailed geology, lifelines, transportation	Land use planners, regional agencies, growth management agencies, utilities	Peak Ground Acceleration (PGA)/ Peak Ground Velocity (PGV)/ Peak Ground Deformation (PGD)	Requires input from a geologist
4. Understand extent of injuries and fatalities	Multiple Scenarios	Level 2, detailed geology and building inventory, essential facilities, schools, hospitals	Medical agencies, emergency managers, risk managers	Casualties by structure type	Requires input from a geologist
5. Assess performance of emergency shelters	Local Scenario	Level 2, detailed geology and building inventory	Land use planners, risk managers, emergency planners	Structural damage	Requires input from a geologist
6. Assess performance of fire stations	Local Scenario	Level 2, detailed geology, fire station inventory, water system	Fire officials, emergency managers, planners	Number of ignitions, area burned, essential facilities damage, water utility damage	Requires input from a geologist, water system engineer, structural engineer to classify structures
7. Identify infrastructure vulnerability	Regional Scenario	Level 2, detailed geology and building inventory	Utility companies, emergency planners, transportation agencies	Utility damage and recovery, transportation system damage	Requires input from a geologist, structural engineers and architects
8. Understand overall building damage	Local Scenario	Level 2, detailed building inventory, essential facilities, schools, hospitals	Land use planners, elected officials, emergency and facility managers	Damage by building type and location, utility, transportation system damage	Requires input from engineers, architects, building officials and planners
9. Set mitigation program priorities	Local Scenario	Level 2, detailed geology, building inventory	Land use planners, risk managers, fire safety officials	Multiple runs of building damage	Requires input from a geologist, structural engineers and architects

HAZUS for assessing common mitigation measures. For example, if your community wants to conduct a study of mitigation requirements for emergency shelters, Table 3 shows that Level 2 data in the form of soils data and local inventory is required for assessing shelter performance in an earthquake. Typically as mitigation measures are identified and refined, an improved representation of the actual conditions in your community is needed.

Improving Mitigation Analyses by Modifying HAZUS' Databases

A community-specific inventory of buildings, or groups of buildings (e.g., fire stations, a defined district, critical facilities), is required for developing details of a program to reduce structural damage and loss. More detailed geologic and soils information and the building inventory data will give your community a more accurate view of its vulnerability to earthquake damage so appropriate local mitigation measures can be determined.

HAZUS contains national inventory information for the building stock of the U.S., but it requires upgrading to be more locally accurate. Within HAZUS are tools to be used with field work, examination of local records and in consultation with local experts for collecting building inventory data for your community and uploading it into HAZUS. For example, incorporating local county tax assessor data can upgrade the square footage by occupancy per census tract, building count by occupancy per census tract, and dollar exposure and occupancy mapping for your community's general building stock. Adding local data and modifying existing national data and parameters within HAZUS will enhance the accuracy of HAZUS outputs. The following are suggested data improvements:

Add geologic hazard data
- ✔ Add soils map
- ✔ Add local liquefaction, landslide, and surface fault rupture maps

Improve general building stock data
- ✔ Modify occupancy class to model building type scheme to more accurately reflect local construction
- ✔ Update census tract values of aggregate building count, square footage, and dollar exposure
- ✔ Enhance seismic design level and construction quality data

Modifying HAZUS Data Bases

Modifying the HAZUS databases to characterize in detail a study area is a formidable task because of the time and effort required to collect large amounts of information and input these data into HAZUS. Suggestions concerning the collection of data and the steps required for inputting are covered in the User's Manual.

Local land-use planners and engineers working together with a GIS specialist can more readily achieve improvements to the HAZUS database just by using professional judgement. A first step is to examine the default databases, as explained in section 7.2 of the Users Manual. Section 7.3 tells how these databases can be modified "manually." For example, by working with Figure 7.4, the mix of building heights and seismic resistances can be tailored to fit local knowledge. By following instructions in section 7.4, different new database mapping schemes can be applied to different groups of census tracts. This approach can significantly improve upon a Level 1 loss estimate without a long delay while large quantities of data are acquired, and may even reduce the need for such effort.

Improve school, emergency response center and hospital data
- ✔ Add shelter and kitchen capacity and building area for schools and emergency response centers
- ✔ Add number of students for schools
- ✔ Add beds for hospitals
- ✔ Add number of trucks for fire stations
- ✔ Add building structural data
- ✔ Add year built
- ✔ Add number of stories for emergency response centers
- ✔ Add backup power capability
- ✔ Include replacement costs

Improve transportation lifelines data
- ✔ Add highway and rail segments, bridges and tunnels
- ✔ Add rail, bus, port, ferry and airport facilities
- ✔ Add airport runways
- ✔ Add dollar exposure.

Improve utilities lifelines data
- ✔ Add pipelines for water, waste water, oil and gas
- ✔ Add electric and communication lines
- ✔ Add water, waste water, oil, gas, electric and communication lifeline facilities
- ✔ Add dollar exposure

Developing occupancy to model building type mapping schemes (assigning building types to occupancies) that accurately reflect your community will require combining available data with input from local experts. The occupancy-mapping scheme is a group of tables designed to describe the building stock by occupancy, structural building type,

> "There is an urgent need to develop an inventory of buildings in seismically active areas of the U.S. to identify where non-ductile concrete buildings and other vulnerable structures (e.g., unreinforced masonry and open-first-story timber frame apartments) are located. All citizens should have access to knowledge about the buildings they live and/or work in, but this type of inventory is not currently available."
>
> Thomas O'Rourke
> Testimony to Congress;
> Hearing: The Turkey, Taiwan, and Mexico City Earthquakes;
> Lessons Learned

and location. National data in the tables are based on ATC-13 (an Applied Technology Council report, *Earthquake Damage Evaluation Data for California*), proprietary insurance data, expert opinion, and inferences drawn from tax assessor's records. Further information on occupancy mapping is provided in Chapter 7 of the HAZUS *User's Manual.*

The Building Data Inventory Tool (BIT) described in Chapter 8 of the HAZUS *User's Manual* has a utility that develops occupancy to model building type mapping schemes from tax assessor's data or other commercially available property data. Collecting supplemental information about local building practices through the use of a questionnaire and/or a workshop also is recommended.

Additional lifeline data are required to use HAZUS' Potable Water System Analysis Model (POWSAM) as described in Chapter 9 (pp. 9-33, 34) of the *HAZUS User's Manual*. POWSAM is a sophisticated tool primarily meant for use by engineers at Level 2 only.

Land-Use and Geologic Hazards

Earthquake risk reduction measures that involve land-use planning provide your community with opportunities to mitigate the potential effects of earthquakes on buildings and infrastructure. Such measures are oriented toward future development, although some can be applied to reusing land or redeveloping portions of your community.

Land-use planning measures are embodied in development policies, community plans, hazards information for the public and those interested in developing parcels, or regulations restricting or prohibiting all or some types of developments in specific hazard areas. Commonly applied land-use and planning-related mitigation measures are indicated in the shaded box. Planning measures are particularly effective in mitigating losses from earthquake-induced ground failures, such as fault rupture, landslides and liquefaction.

Land-Use Planning and Geologic Hazards Mitigation Measures

Land-Use Planning Mitigation Measures

- Identify seismic safety/geologic hazards/natural hazards in general plans.
- Enact zoning ordinances consistent with general plans that regulate densities and uses in hazardous districts or parcels.
- Adopt subdivision regulations that set lot patterns to avoid geologic hazards.
- Adopt grading regulations that prescribe limits on excavations or fills for building sites.
- Apply special development regulations that recognize that some parcels are more suitable for building than others in designated areas.
- Recognize in local capital improvement programs and budgets earthquake hazards that influence the location, timing and pace of new development and public facilities.
- Ensure that environmental and related impact analyses address earthquake hazards and include effective mitigation measures.
- Redevelop areas to replace deteriorating and unsafe buildings with new construction that also avoids geologic hazards.
- Designate open spaces in urban areas for firebreaks, evacuation areas, emergency housing sites, temporary hospitals, and post-earthquake supply distribution centers.

Geologic Hazards Mitigation Measures

- Develop detailed hazard and ground-failure maps for local use.
- Recommend hazard avoidance mechanisms, such as setbacks or “special studies zones” where detailed geologic reports may be needed.
- Provide specialized design and construction techniques, where required, for site-specific mitigation: dewatering, removal and replacement of soils, grading, construction on pilings, adding retaining walls or other barriers and foundation design.
- Establish adequate internal and independent project review procedures for geotechnical reports.
- Record and disclose site conditions or hazards before issuing permits or transferring ownership of properties.

Where the ground is subject to surface fault rupture, landslides, liquefaction, slumps, lateral spreading, amplified ground shaking or flooding, your community should consider implementing geotechnical mitigation measures as summarized in the shaded box. The principal measures involve avoiding potentially hazardous locations or modifying the soil under or near new or existing building sites to enhance their earthquake resistance. Implementing these measures requires input from seismologists to identify and characterize fault breaks and geotechnical engineers to describe soil conditions.

Using HAZUS and Land-Use Planning for Mitigation

Let us look at how the graphic information that HAZUS produces might support the adoption and implementation of planning-related measures. Figures 1 and 2 demonstrate how an earthquake impacts communities within the region vary differently depending on their location, demographics, building stock, and other variables. Based on this analysis, neighboring communities may choose to adopt different risk reduction measures.

Figure 1 shows land-use/land cover data from HAZUS' Supplemental Data mapped on a study region generated by HAZUS. Supplemental Data sets provide land use/land cover maps for each U.S. state that can, through GIS, be overlaid with user-supplied maps for soils, liquefaction, and landslide as well as HAZUS-generated ground shaking maps to identify areas of existing or planned development that may be at risk for damage and loss.

Figure 1 – Sample HAZUS Map: Land-Use/Land Cover

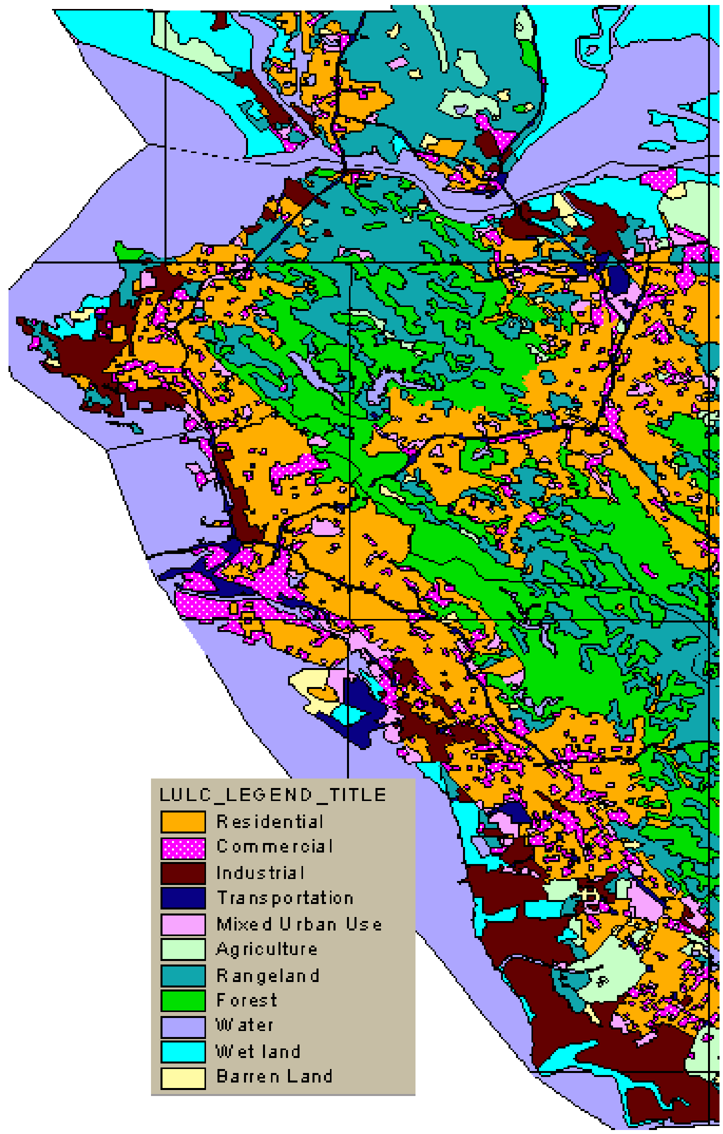
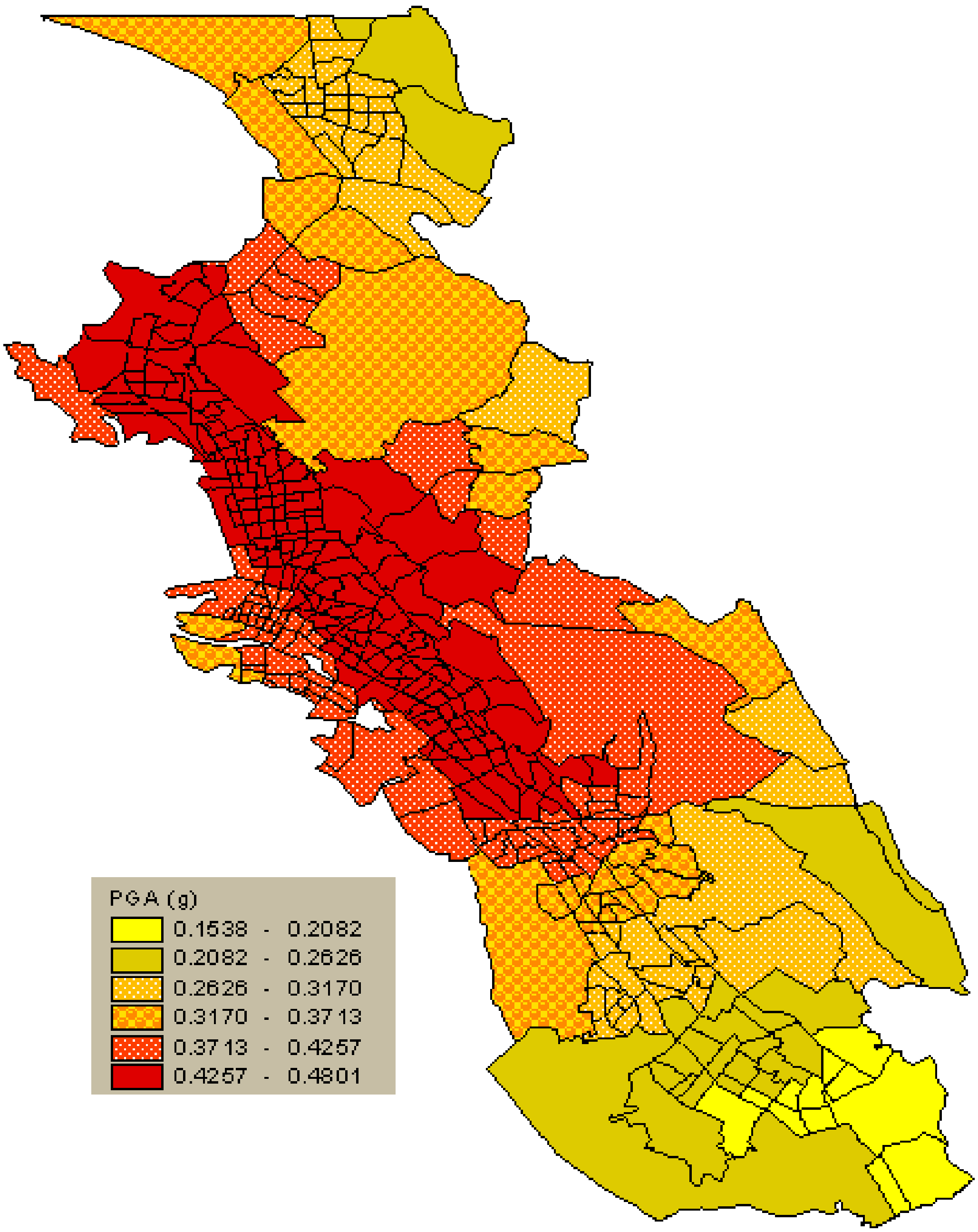


Figure 2 shows the same study region with anticipated ground-shaking

Figure 2 – Sample HAZUS Map: Ground Shaking by Census Tract



generated by HAZUS by census tract. Several observations may be drawn by comparing the two maps: 1) The region's commercial district largely lies in the second highest area of anticipated shaking; 2) The industrial area at the top of the map lies largely in the area of highest anticipated shaking while the industrial area at the bottom of the map lies mostly in the area of the lowest anticipated shaking; and 3) Most of the residential building stock is in the area of the highest anticipated shaking.

Using this information, local officials could, for example, consider a mitigation program to preserve structures in the commercial district and the higher-risk industrial region. An ordinance might be enacted to demolish abandoned buildings, and, assuming that the forested area bordering the residential area is mountainous, subdivision regulations may be enacted to restrict building on or near steep slopes.

Additionally, for mitigation planning, community development representatives can analyze the community's historic evolution, current configuration, future development patterns, and current growth management policies and determine economic impacts in light of potential hazards issues. The conclusions from this analysis might be used in the development of capital improvement programs.

Using HAZUS and Geologic Hazards Analysis for Mitigation

HAZUS can be used to identify geotechnical mitigation strategies. HAZUS provides nationally based data on active earthquake faults and expected ground motions and assumes an average soil condition for the entire U.S. For a more refined estimation, seismologists can input into HAZUS information on locally known active faults. Geotechnical engineers can input site-specific information on potential liquefaction, landslides, and soil amplification.

Figure 3 demonstrates how levels of ground shaking shown in Figure 2 are increased by inputting local soils data into HAZUS. Observations on the effects of an earthquake drawn in the land-use planning section using Figure 1 may be revised as follows: 1) The region's commercial district now totally lies in the second highest area of anticipated shaking; and 2) The industrial area at the bottom of the map will experience considerably increased anticipated shaking.

HAZUS and Local Soil Conditions

Local soil conditions will, in many communities and regions, have a major effect upon the losses caused by earthquakes, and especially upon the geographical distribution of these losses. Using HAZUS, it is possible to enter the soil conditions approximately and simply, or to use maps prepared after detailed studies.

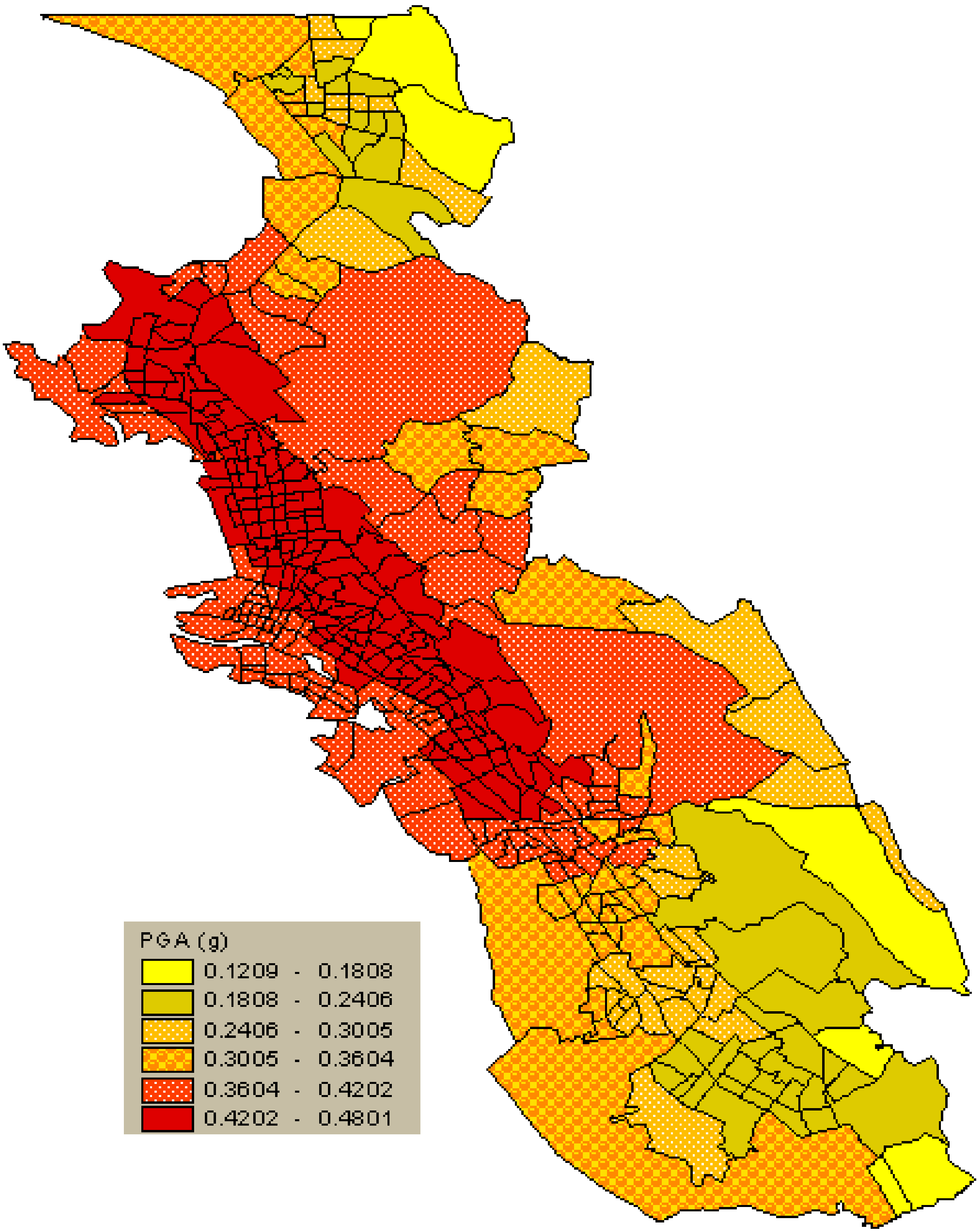
At the simplest level, local experts may use their experience and judgement to assign a soil type and a liquefaction susceptibility to each census tract.

If soil type and liquefaction susceptibility maps are available, they may be entered directly into HAZUS, after converting them to the proper format. This step will require expertise in the use of GIS.

It will be necessary to assess carefully results from any census tract where pockets of hazardous soils exist under buildings since HAZUS can only have a single soil type for each census tract.

HAZUS includes the means for analyzing the effects of landslides for areas with unstable slopes.

Figure 3 – Sample HAZUS Map: Ground Shaking with Soils



Based on this new information, waterfront areas in the commercial district with increased potential shaking due to poor soils might be set aside as parkland or for recreational use. Planners, developers, engineers and architects, alerted to higher levels of potential shaking in the industrial district, might want to perform engineering analyses to formulate specialized design and construction mitigation techniques such as dewatering or removal and replacement of soils. Building officials might implement stricter engineering reviews regarding the adequacy of building foundations for a chosen site.

As another example, Figure 4 shows unreinforced masonry buildings (URMs) largely concentrated in an area characterized by poor ground subject to liquefaction (see Figure 5) which amplifies motions. Planners might consider amending the general plan and zoning regulations to designate this area for low density uses, such as for marinas, parks, open space, wildlife refuges, and small buildings. Additionally, geotechnical and engineering analyses might be done to determine the earthquake vulnerability of these existing potentially hazardous buildings and the need to strengthen, replace, or otherwise reduce losses.

Figure 4 – Sample HAZUS Map: Casualties from URMs

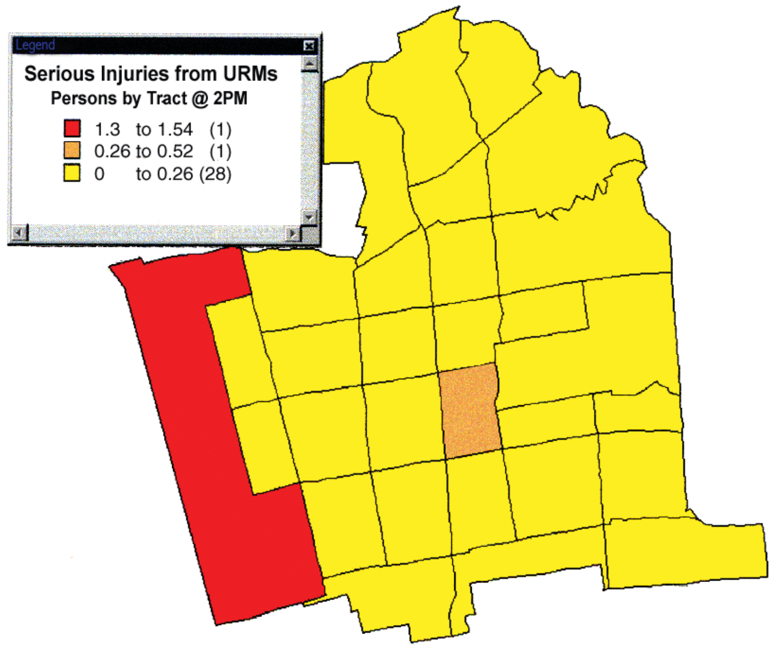
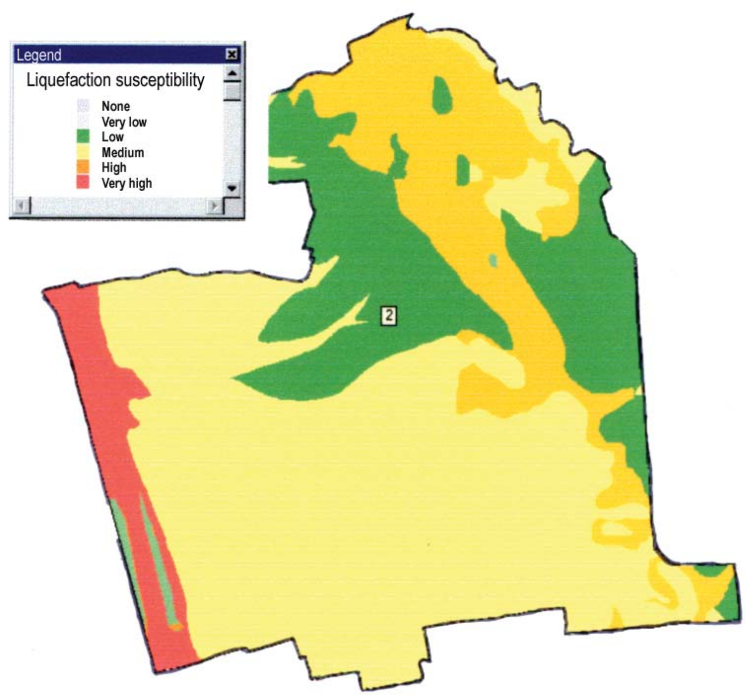


Figure 5 – Sample HAZUS Map: Liquefaction Susceptibility



Buildings

Perhaps the most common mitigation measures taken by communities are related to the seismic resistance of buildings. Significant reduction of losses can be achieved both by improving seismic design and construction of new buildings and by rehabilitating or replacing older buildings.

The most obvious action to be taken for new buildings is to adopt and enforce the seismic provisions of the latest model building codes. Although only a small percentage of the total buildings in a region are "new" each year, losses in future earthquakes can be greatly reduced by establishing good seismic building practices. On the other hand, a community that does not adopt or enforce seismic standards is increasing its risk every day. Special seismic provisions can also be adopted for certain important buildings (sometimes called essential buildings) such as hospitals, schools, police stations, and emergency operations centers. Design provisions for these building are more stringent than

Building Mitigation Measures

Structural Mitigation Measures

- Develop local inventory and identify hazardous building types.
- Adopt building codes with seismic provisions governing design and construction of new buildings.
- Enforce compliance with building codes and construction quality standards.
- Adopt building code provisions to require seismic retrofit at times of significant renovation or change of occupancy.
- Adopt ordinances to mitigate potential falling hazards on streets and sidewalks (roof-top tanks, parapets, cladding, etc.)
- Adopt ordinances requiring retrofit within specified time limits.
- Adopt ordinances for seismic retrofit of various types of high-risk buildings.

Nonstructural Mitigation Measures

- Identify high risk or potentially high dollar loss nonstructural systems.
- Adopt ordinances to reduce falling hazards in public places (warehouse stores, etc.)
- Develop and make available self-help information for mitigation of nonstructural elements.
- Develop programs to provide anchorage and restraint of furniture and other contents.

Essential Facilities Mitigation Measures

- Seismically evaluate essential facilities such as schools, hospitals and emergency response centers.
- Develop programs to improve the seismic performance of essential facilities by retrofit or replacement.
- Develop programs to improve the seismic performance of nonstructural systems in essential facilities.

for average buildings and are intended to allow continued use of the facility immediately after an earthquake.
By far, the most risk in typical communities comes from older buildings that were not designed to modern seismic standards. Of particular concern as life safety risks are older unreinforced masonry buildings and concrete buildings not designed to seismic standards. Mitigation of the risks from the existing building stock can range from redevelopment or replacement of entire neighborhoods to programs that target the highest risks (e.g. bracing or removal of parapets and other falling hazards) to programs that require rehabilitation of certain vulnerable buildings types (e.g. unreinforced masonry or hillside private residences).

The identification of realistic and effective programs to mitigate risks in existing buildings requires knowledge of the type and extent of different building types in your area, their probable vulnerability to earthquake damage, their location with respect to expected earthquake shaking, and the costs of rehabilitation in terms of dollars and disruption of use. HAZUS can help a community determine the risks, but detailed analysis of proposed programs, including costs and schedules, can only be determined at the local level with extensive community-specific analysis.

Table 4 - Modeling in HAZUS of Mitigation Measures for Existing Buildings, lists mitigation actions on existing buildings that have been considered by other communities and gives an indication of the ability of HAZUS to model the conditions. It can be seen that HAZUS is best at modeling complete rehabilitation measures (e.g., completely rehabilitate all unreinforced masonry buildings) as opposed to measures that affect only one aspect of a building's seismic safety (e.g., brace chimneys or anchor water heaters).

Using HAZUS for Structural Mitigation

General Use of HAZUS: Maps and tables generated by HAZUS are particularly useful for making decisions about structural mitigation measures. The most basic form of mitigation analysis using HAZUS is to identify portions of your community where buildings are expected to incur the most damage and economic losses. Most of the damage and loss outputs from HAZUS can be displayed and mapped by census tract for classes of buildings or by individual facility. This information can be used to direct further engineering studies to identify specific problem structures and to develop appropriate mitigation measures. See *Table 1 - Direct Economic Losses for Buildings* for an example of a typical building losses report that lists expected dollar losses for structural, non-structural, and contents damage to buildings for a city.

Table 4 - Modeling Mitigation Measures in HAZUS for Existing Buildings *(See notes at end of table)*		
Model Building Type	**Mitigation Measure**	**Use of HAZUS**
Residential wood	Bolting sills to foundation	Difficult to model mitigation of a specific building element with HAZUS global building techniques; in addition, mitigation may affect only a small percentage of MBT.
Residential wood	Bolting as above and bracing cripple walls	Although this is mitigation of a specific building element, global behavior is affected. An optimistic first cut estimate of improvement can be obtained by comparing *No Code* with *Moderate Code*. This estimate can be improved if the percentage of the MBT with this deficiency was determined and modeled separately. Best if BSDLF is used.
Residential wood	Support and bracing of hillside homes	This is a unique subcategory of MBT. Use of BSDLF is necessary.
Residential wood	Bracing of URM chimneys (above roof)	Difficult to model mitigation of a specific building element with HAZUS global building techniques. Must consider the element by itself as a “building” and develop BSDLF.
Residential wood	Replacement of URM chimneys	Difficult to model mitigation of a specific building element with HAZUS global building techniques. Can consider the element by itself as a “building” and develop BSDLF.
Residential wood	Mitigation of hazards from gas, such as bracing water heaters or installing shut off valves.	Difficult to model mitigation of a specific building element with HAZUS global building techniques. Can change number of ignitions in fire module to estimate improvement.
Residential wood	Complete rehabilitation (foundation and superstructure)	A first cut estimate of improvement can be obtained by changing *No Code* to *Moderate Code*.
Residential URM	Complete rehabilitation	Residential URMs are not well represented in the existing MBTs. URM structural characteristics may overestimate damage to residential URMs. A first cut estimate of improvement can be obtained by comparing *URM No Code* with *Reinforced Masonry Moderate Code.* BSDLF recommended.
URM	Brace parapets	Difficult to model mitigation of a specific building element with HAZUS global building techniques. Can consider the element by itself as a “building” and develop BSDLF. Risk of casualties is not directly related to building occupancy as modeled by HAZUS.
URM	“Bolts Plus” programs	Difficult to model mitigation of a specific building element with HAZUS global building techniques. Can obtain an optimistic first cut estimate of improvement for low to moderate shaking levels by comparing *URM No Code* with *Reinforced Masonry Low or Moderate Code.* Improvement for high levels of shaking is expected to be much less and is difficult to model without BSDLF.
URM	Complete rehabilitation: life safety standard	A first cut optimistic estimate of improvement can be obtained by comparing *URM No Code* with *Reinforced Masonry Moderate Code*. Lower bound improvement can also be estimated by comparing *URM No Code* to *Reinforced Masonry Low Code*

Table 4 - Modeling Mitigation Measures in HAZUS for Existing Buildings
Continued *(See notes at end of table)*

Model Building Type	Mitigation Measure	Use of HAZUS
Tilt-ups (west coast style; actual construction characteristics vary across country)	Primarily mitigation of out-of-plane wall and related roof collapses.	A first cut estimate of improvement can be obtained by comparing *No Code* with *Moderate Code.* Characteristics of local tilt-ups should be confirmed to include out of plane wall anchorage deficiencies. This estimate can be greatly improved by specific consideration of local building characteristics and proposed rehabilitation measures by developing BSDLF.
Nonductile concrete, particularly frames	Complete rehabilitation: life safety standard	A first cut estimate of improvement can be obtained by comparing *No Code* with *Moderate Code*.
Precast garages	Complete Rehabilitation: life safety standard	A first cut estimate of improvement can be obtained by comparing *No Code* with *Moderate Code*.
Concrete with masonry infill	Complete rehabilitation: life safety standard	A first cut estimate of improvement can be obtained by comparing *No Code* with *Moderate Code*.
Steel frame with masonry infill	Complete rehabilitation: life safety standard	A first cut estimate of improvement can be obtained by comparing *No Code* with *Moderate Code*.
Steel welded moment-resisting frame	Complete rehabilitation: life safety standard	A first cut estimate of improvement can be obtained by comparing *No Code* with *Moderate Code*. Damage and loss functions derived from Northridge earthquake damage to modern steel welded steel moment frames is not currently incorporated into HAZUS. BSDLF have been developed as part of the FEMA sponsored SAC Steel Project, and should be used to estimate the results of mitigation to this subset of the MBT.

MBT: HAZUS Model Building Type
BSDLF: Building Specific Damage and Loss Functions
SAC: A joint venture of the Structural Engineers Association of California, the Applied Technology Council, and Califirnia Universities for Research in Earthquake Engineering
No Code: Use mapping scheme parameters of *Low Seismic and Inferior Building Quality*
Moderate Code: Use mapping scheme parameters of *Moderate Seismic and Code Building Quality*
Low Code: Use mapping scheme parameters of *Low Seismic and Code Building Quality*

Another tool for estimating life-safety risks and other impacts are HAZUS' building damage states for structural building types. There are five damage states in HAZUS to describe the nature and extent of damage to the building's components (e.g., beams, columns, walls, ceilings): none, slight, moderate, extensive or complete. Building damage states might be used to study expected damage patterns in a given region for different scenario earthquakes to identify the most vulnerable building types or the areas with the worst expected damage to buildings. This information might then be used to plan in-depth studies of vulnerable areas and the building types therein to determine appropriate mitigative courses of action such as undertaking major structural rehabilitations or strengthening building components. Further information on damage states can be found in the HAZUS User's Manual in section 9.4.2, and in section 5.3 of the Technical Manual. Section 5.3.1 of the Technical Manual provides general descriptions of the structural damage states for a number of typical building types.

Specific Modeling Suggestions: HAZUS will identify risks presented by the local building stock, and it can be used to estimate the results of broad mitigation actions aimed at vulnerable existing buildings or new buildings represented by future development.

The order of magnitude of reduced losses that can be achieved by seismically rehabilitating all buildings or specific types contained in the active inventory (or by incorporating seismic design provisions in future buildings) can be estimated by changing HAZUS' building mapping scheme parameters. In HAZUS, expected seismic performance of a given Model Building Type (MBT) is determined by the combination of the parameters measuring the appropriate code level for the area: *Low, Moderate, and High Seismic* and the Quality Factors: *Code, Inferior, and Superior*. These parameters are discussed more fully in Chapter 7 of the User's Manual and Chapter 5 of the Technical Manual. Although all of the combinations of these factors can create a total of nine variations (3 x 3), only the following four are recommended for use for testing the significance of various mitigation measures for the building inventory.

- *Low Seismic-Inferior*—used to describe buildings with no seismic design ("No Code")
- *Low Seismic-Code*—used to describe buildings designed to modern codes in UBC Seismic Zone 1 or NEHRP map area 3 or lower ("Low Code")
- *Moderate Seismic-Code*—used to describe buildings designed to modern codes in UBC Seismic Zone 2B or NEHRP map area 5 ("Moderate Code")
- *High Seismic-Code*—used to describe buildings designed to modern codes in UBC Seismic Zone 4 or NEHRP map area 7 ("High Code")

Incorporating seismic design into new building construction, or accomplishing seismic rehabilitation of existing buildings will not eliminate the losses but only reduce them. Therefore, the reduction in losses stemming from a mitigation measure cannot be taken as the total loss initially attributed to a given building type or inventory, but is always the difference between the original condition and the mitigated condition. There is little damage data from actual earthquakes on the reduction of losses from mitigation actions. Thus, short of an extensive local study of conditions, improvements can only be roughly estimated by comparing HAZUS runs for different inventory conditions. For the purposes of these estimates, the following changes in inventory parameters are recommended:

1. To test the effect of adopting seismic design for new buildings, enter into HAZUS estimated new development in appropriate locations (in HAZUS by census tracts) and with the expected model building types. Compare losses with the future inventory characterized as *No Code* to that of *Low, Moderate, or High Code*, as applicable to your area.

2. To test the effect of seismic rehabilitation on the inventory or on a specific model building type, compare results with inventory entered as *No Code* to that of *Moderate Code* (in all areas). Seismic performance objectives of local rehabilitation ordinances vary greatly, and it is difficult to capture such variations. A reasonable initial estimate of loss reduction potential from rehabilitation can be obtained with use of the *Moderate Code* description. However, before adoption of mitigation measures, it is recommended that the benefits and costs be estimated locally. This is beyond the model building type calculations of HAZUS.

For the specific model building type of unreinforced masonry construction (URM), it is recommended to compare results with this portion of the inventory entered as *URM-No Code* to the same inventory entered as *Reinforced Masonry-Low Code* for a lower bound estimate of improvements, and to *Reinforced Masonry-Moderate Code* for a upper bound estimate of improvements. A variety of mitigation actions for various specific model building types that have previously been considered or used are listed in Table 4, along with comments concerning the use of HAZUS to study their differing effects.

In earlier versions of HAZUS (HAZUS97, HAZUS99, and HAZUS99-SR1), building value depends soley on occupancy class rather than model building type. These earlier versions calculate an aggregate, although the total loss to the occupancy is calculated correctly, the reassignment of losses to each model building type will not directly reflect changes in performance due to

Building Specific Damage and Loss Functions

HAZUS incorporates 36 Model Building Types (MBTs) of three different height ranges to model a building inventory. In addition, each of these MBTs can be classified by various seismic design attributes, depending on applicable local codes. Expected seismic response, economic value, occupancy, and damage characteristics for each case are embedded in HAZUS. Because HAZUS is a national loss estimation program, there are groups of buildings in various communities that may not be modeled well. In addition, the many different degrees of seismic rehabilitation that can be accomplished are not specifically modeled. However, it is possible in the current version of HAZUS to enter all the parameters necessary to model a unique specific building or group of buildings. These parameters are termed Building Specific Damage and Loss Functions (BSDLF). Earthquake engineering expertise is needed to develop these parameters, and expert knowledge of HAZUS is required to enter the parameters and to examine the results. HAZUS users can contact NIBS for further information on this advanced use of HAZUS. It is expected that this capability will be made more user-friendly in future versions of HAZUS changes in code and quality factors of a single model building type. It is, therefore, recommended to study only the changes in total losses in building stock due to mitigation measures, or to zero out all model building types other than the one (or group) under study. However, this procedure is no longer required starting with HAZUS99-SR2, since building values now are assigned explicity to model building types in addition to occupancies.

A Level 1 loss estimate, using default building inventory, may yield useful overall regional losses, but the results may not be representative when broken down by specific census tracts, building occupancies, or model building types. Promising mitigation schemes must be pursued further using analysis methods incorporating more detail about the inventory itself and considering the applicability of the loss and damage functions of the preset HAZUS model building types. These recommended approaches require the following steps:

1. Run loss estimates using the building inventory within the default database. Investigate various mitigation actions by revising the Seismic/Quality Factors of appropriate portions of the inventory and comparing losses. The significance and value of improvements should be considered based on reviewing the performance of the isolated portion of the inventory affected, rather than changes in overall regional losses, which for many mitigation measures, may be small. The effect of changing seismic design criteria on future construction can be estimated by creating an inventory that will represent expected future development and by making comparisons of losses using various Seismic/Quality Factors.

2. If estimates of improvements using default inventory are promising, investigate the applicability of the default inventory for local conditions. This is most easily done by convening a small group of persons knowledgeable about local building stock, such as real estate personnel, building officials, and architects and engineers. Rerun "before and after" conditions using an improved representation of local building stock. It is also recommended that local soil conditions be utilized for these Level 2 runs.

3. HAZUS results can be made even more applicable to local conditions by collecting more exact information on the buildings proposed for mitigation. Numbers of buildings and square footage per census tract can be collected, the data converted to HAZUS inventory descriptions, and additional comparison runs can be made.

4. If more information is necessary or desirable, seismic structural experts can review HAZUS damage and loss functions for applicability to the building stock being studied. If

not adequate, building specific damage and loss functions (BSDLF) can be developed for use in HAZUS or detailed studies of costs and benefits of the mitigation measure can be performed outside the framework of HAZUS.

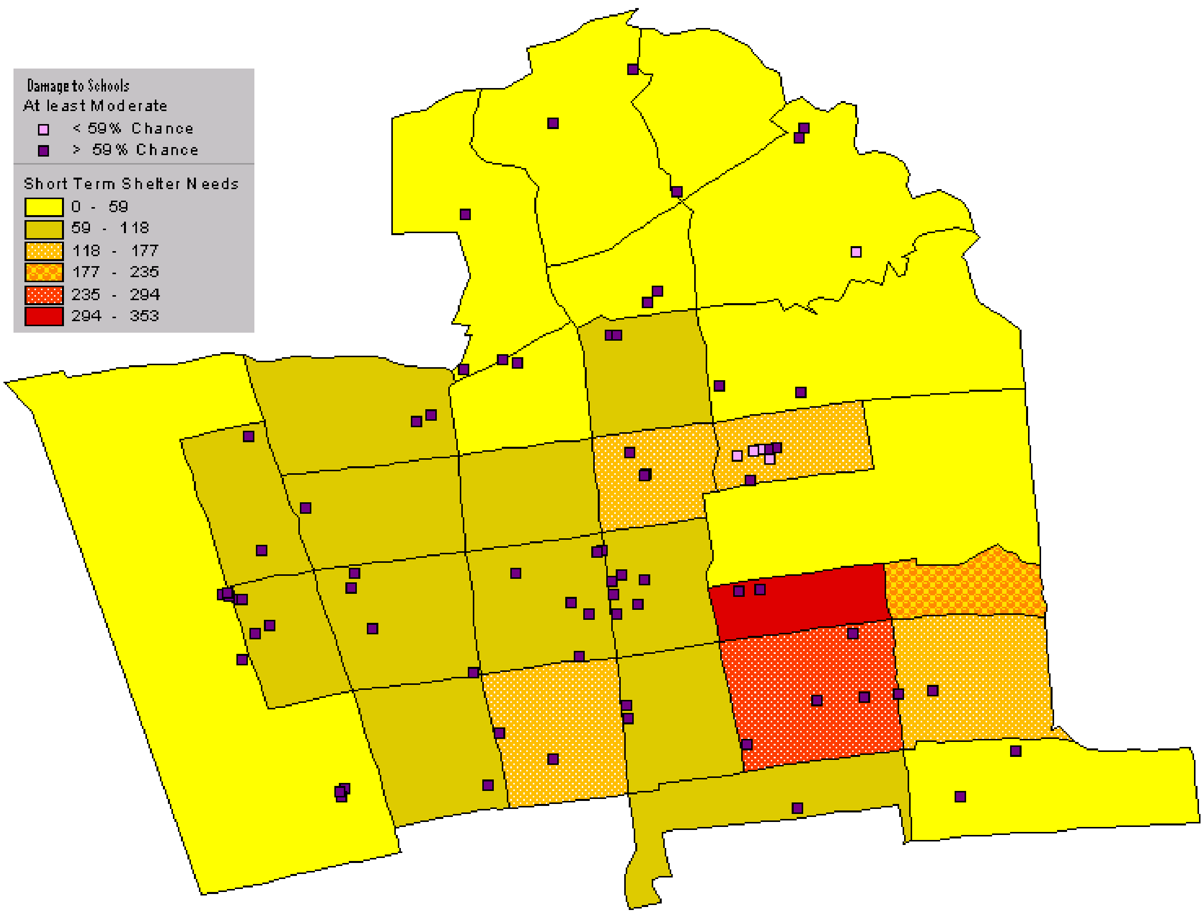
5. Starting with HAZUS99-SR2, an Advanced Engineering Building Module (AEBM) is available to support mitigation efforts by providing building-specific loss estimation tools for use by experienced seismic/structural engineers. HAZUS damage and loss functions for generic model building types are considered to be reliable predictors of earthquake effects for the large groups of buildings represented. However, more directed analysis is required to adequately predict damage for a specific building or groups of buildings that can be described in detail. Using the AEBM procedures in mitigation, an engineer can create building-specific damage and loss functions that can be used to assess single or group building losses both in their existing condition and after some amount of seismic rehabilitation. The accuracy of damage and loss estimates using building-specific functions, and their improvement over predictions using generic building functions, will depend both on the quality and completeness of building-specific data and on ability of the engineer to transform this information into meaningful functions.

Nonstructural Building Components

Nonstructural building components include building mechanical/electrical systems and architectural components such as partition walls, ceilings, windows and exterior cladding that are not designed as part of the building load-carrying system. For future construction, adoption and enforcement of seismic building code provisions will provide requirements for the seismic protection of nonstructural components as well as the structure. For existing buildings, successful mitigation measures have been limited to anchorage of parapets and other falling hazards (although often considered "structural" mitigation), and anchorage of residential water heaters. Mitigation consisting of anchoring a significant portion of nonstructural components in the general inventory has not been attempted. On the other hand, nonstructural programs targeted at essential buildings such as schools, hospitals, and emergency command centers have been successful and will greatly enhance the ability of these buildings to perform their post-earthquake roles.

HAZUS' current focus is more on global changes to buildings, and the program does not easily facilitate the testing of nonstructural mitigation measures. Expected nonstructural performance is largely tied to the structural code and quality levels previously discussed under *Specific*

Figure 6 – Sample HAZUS Map: School Damage and Short Term Shelter Needs



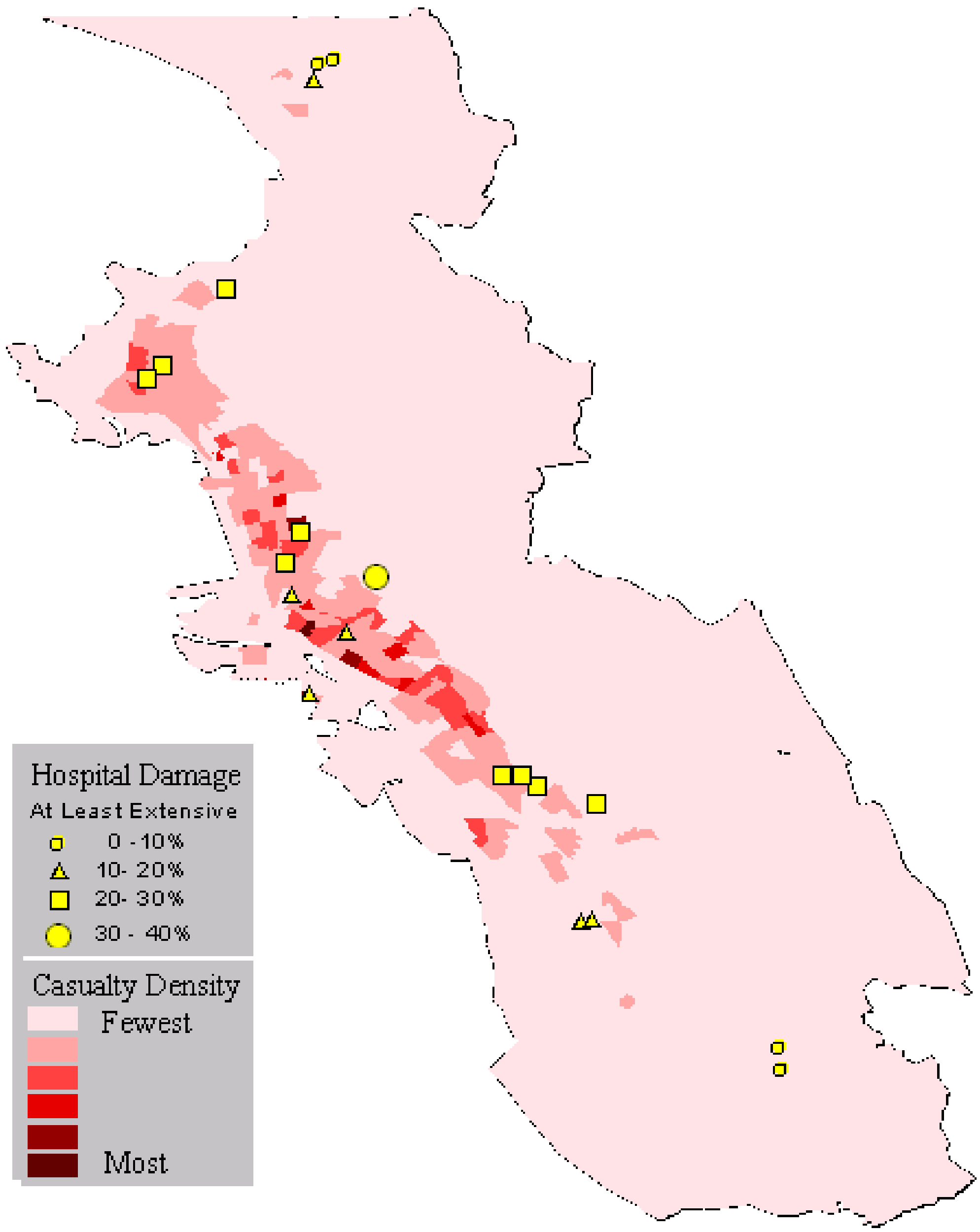
Modeling Suggestions. Future versions of HAZUS may include the ability to more explicitly model changes to the seismic protection levels of nonstructural systems.

Essential Facilities

HAZUS also can be used for mitigation analysis for essential facilities including hospitals, schools and fire and police stations. Maps and summary reports can be used to identify potential damage to these types of facilities after an earthquake and to assess problems with their available service capacity.

In Figure 6, a HAZUS map shows schools that are expected to serve as high occupancy shelters and their expected level of earthquake damage (greater or less than 59%). Your community might evaluate the earthquake resistance of its schools to determine the nature of the expected damage and the implications for life safety and continued functionality for shelter operations. Second, funds might be secured to replace some of

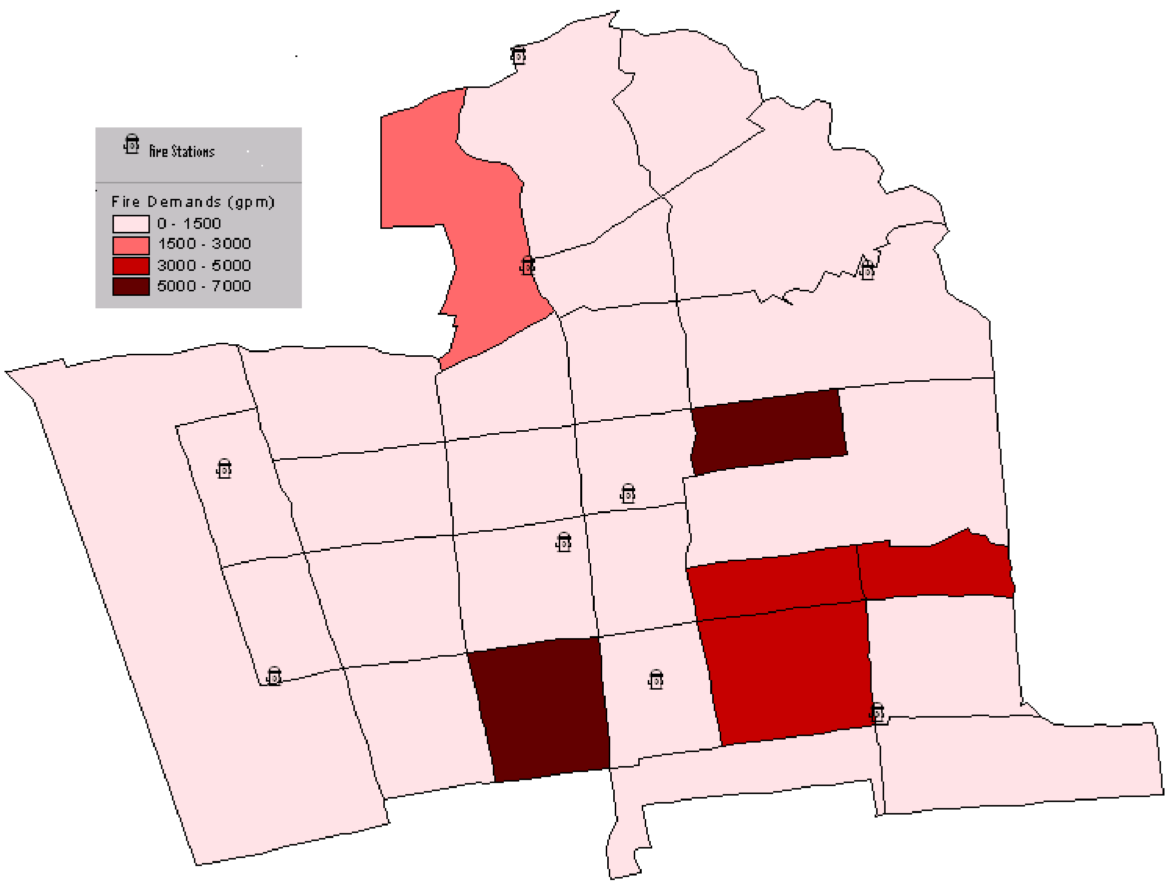
Figure 7 – Sample HAZUS Map: Hospital Damage Overlaid with Casualties Density



school buildings or to mitigate their potential structural and nonstructural damage. And, third, the estimated shelter needs might exceed the schools' capacities, leading city officials to consider evaluating and designating other structures as additional emergency shelters.

Figure 7 shows the location of hospitals in the study region, their expected earthquake damage and the probable concentrations of casualties they will have to serve following an earthquake. Your community might want to structurally evaluate existing hospitals and adopt special standards for up-

Figure 8 – Sample HAZUS Map: Fire Stations and Fire Demand



grading existing or constructing new ones.

In Figure 8, a HAZUS map shows fire station locations and water demands in gallons per minute (gpm), the standard calculation for fire suppression. Potentially high demands (5,000-7,000 gpm) and excessive distances between stations might give your community reason to perform an engineering study of the fire stations to determine which, if any, may need to be replaced or seismically strengthened. Also, working with the water district, your community might determine what, if anything, needs to be done to improve the earthquake resistance of the water storage and distribution system.

For using the methods described in *Specific Modeling Suggestions* for buildings, the Superior Quality Factor is intended for essential facilities designed for superior performance (e.g., use of an importance factor of 1.5 in building codes). The expected improved performance of essential buildings retrofitted or replaced to that level can be tested by assigning this Quality Factor as appropriate.

Infrastructure

Transportation, water, natural gas, electricity, wastewater, and communications systems make up the infrastructure or lifelines of your community. With their varying configurations and geographic distribution, designing and constructing earthquake-resistant lifeline facilities requires specialized expertise.

Seismically-based standards for mitigating potential losses in many of these systems are few and inconsistent. Often, it is easier to replace old systems or elements rather than trying to strengthen existing ones. Some facilities, such as ports, coastal or flood barriers, and refineries may have to be located in poor ground areas. Specialized geotechnical and earthquake engineering expertise may be needed to ensure effective mitigation. In increasingly dense earthquake-prone urban areas, the impact of an earthquake on transportation, communications, and other systems, especially those having little or no redundancy, will quickly contribute to the losses, add great burdens on emergency response forces and slow early recovery actions. The shaded box lists mitigation measures for lifelines.

Using HAZUS for Transportation and Utility Lifelines Mitigation

Lifelines in HAZUS are divided into transportation systems and utility systems. Lifeline damage is described in terms of probable damage to system components for a given level of ground motion, and as the estimated time required to restore full functionality of the system. HAZUS' simplified analyses for water and electric power systems at Level 1 provides a preliminary assessment of vulnerability. To conduct a detailed Level 2 mitigation study of a community's potable water system, a sophisticated user can employ HAZUS' Potable Water System Network Analysis Model (POWSAM), which was developed to allow the importing of the most widely used water network inventory data.

Incapacitated bridges will contribute to projected economic losses to individual communities within the region. Additionally, they will exacerbate economic losses due to the inability of industrial and commercial entities to serve other regional communities and external markets and employees unable to reach their places of employment from their residences. As with building damage, mitigation analysis for lifelines is

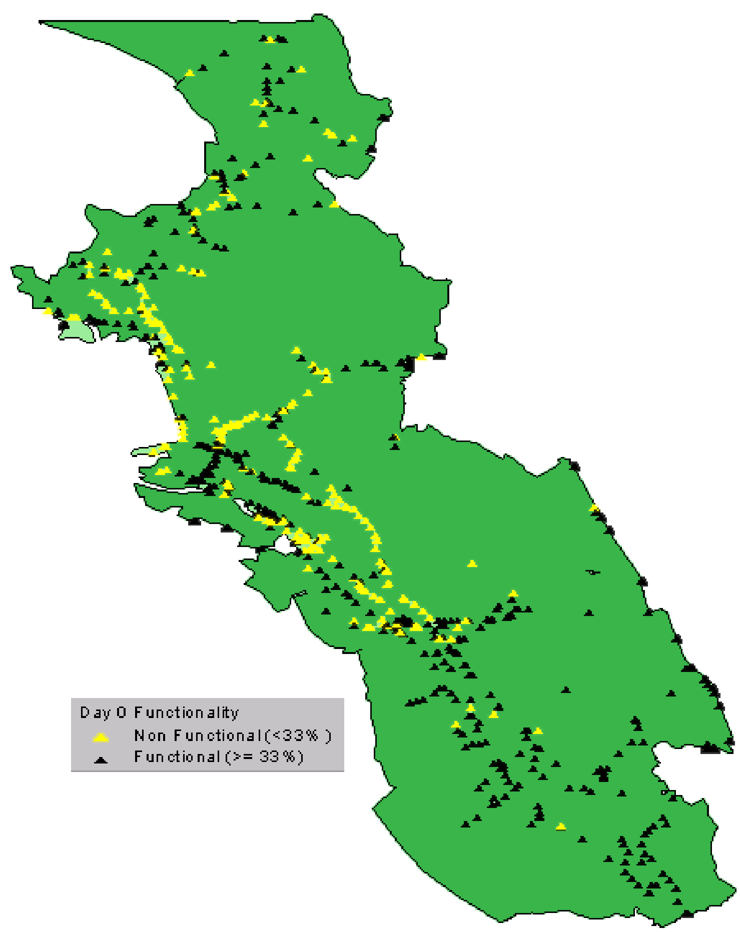
Infrastructure Systems Mitigation Strategies

- **Evaluate the performance of existing lifelines subject to ground motion.**
- **Develop programs to retrofit of replace deficient lifeline components.**
- **Adopt earthquake resistant standards and designs for new community lifelines, including water, transportation, electrical and similar systems.**
- **Design specialized facilities, such as ports, refineries, and others, that are "outside" of building codes for seismic resistance.**

> "It should be recognized that all the major water supply pipelines from external water-sheds for the Los Angeles area cross the San Andreas Fault, and a similar situation pertains to the water supply pipelines for San Francisco crossing either the Hayward or San Andreas faults. East of Los Angeles, the San Andreas Fault crosses Cajon Pass where many vital lifelines (highway; railroad; natural gas, water, and petroleum pipelines; fiber optic lines, and electric power transmission lines) are collocated in a very narrow pass subject to fault rupture."
>
> Thomas O'Rourke
> Testimony to Congress;
> Hearing: Turkey, Taiwan and Mexico City Earthquakes;
> Lessons Learned

performed by examining HAZUS-generated maps, detailed tables of results and summary tables for high-loss features or by comparing losses under unmitigated and mitigated conditions. Figure 9 identifies highway bridges with a poor probability of having functionality restored within a reasonable amount of time after an earthquake. Specific bridges require further study to assess their deficiencies and to formulate specific mitigation measures.

Figure 9 – Sample HAZUS Map: Highway Bridges Functionality



Flood, Hazardous Material and Fire Exposure

Besides building and lifeline-related damage, communities also can incur damage and loss of life from other earthquake-induced hazards: flooding from dam breaks, hazardous material releases and fires.

HAZUS' results may encourage your community to reduce the likelihood of dam or levee failure and to prepare for floods that may occur. As a first step in assessing the risk to your community, HAZUS identifies all dams and levees including a hazard classification (low, significant, high) based on downstream urban development and potential economic loss. In Figure 10, a HAZUS map displays dams in a study region located in soils subject to potential liquefaction. This information might lead your community to evaluate the structural integrity of one of more of the dams. Linked with inundation maps, these analyses could provide a basis for strengthening, replacing, or closing dams or taking precautionary measures, such as lowering their water levels, to avoid earthquake-caused downstream losses in case of the dams' partial or complete failure. Inundation maps, an essential element in accurately assessing a community's risk, are not produced in HAZUS. HAZUS has the capability, however, to import existing inundation maps which can be overlaid with population density maps or maps of inventory to estimate exposure.

HAZUS maps the locations of hazardous material facilities as shown in Figure 11 or in conjunction with ground motion, soils, population, and inventory maps. HAZUS also identifies the types and amounts of stored materials. Your community might conduct a preliminary assessment of potential consequences to highly vulnerable facilities, which can be followed up with detailed, site-specific studies. At a higher level of analysis, a plume (dispersion) map can be input into HAZUS to demonstrate exposure of populations to hazardous materials releases.

For fire-following-earthquake, HAZUS provides estimates of the percentage of burned area, number of ignitions, the population exposed, the dollar value exposed and fire demand in gallons per minute (gpm). With this information, your community might consider purchasing additional fire and specialized HAZMAT response apparatus or providing automatic gas valves that shut-off in the event of shaking.

Figure 10 – Sample HAZUS Map: Dams Overlaid with Liquefaction Potential

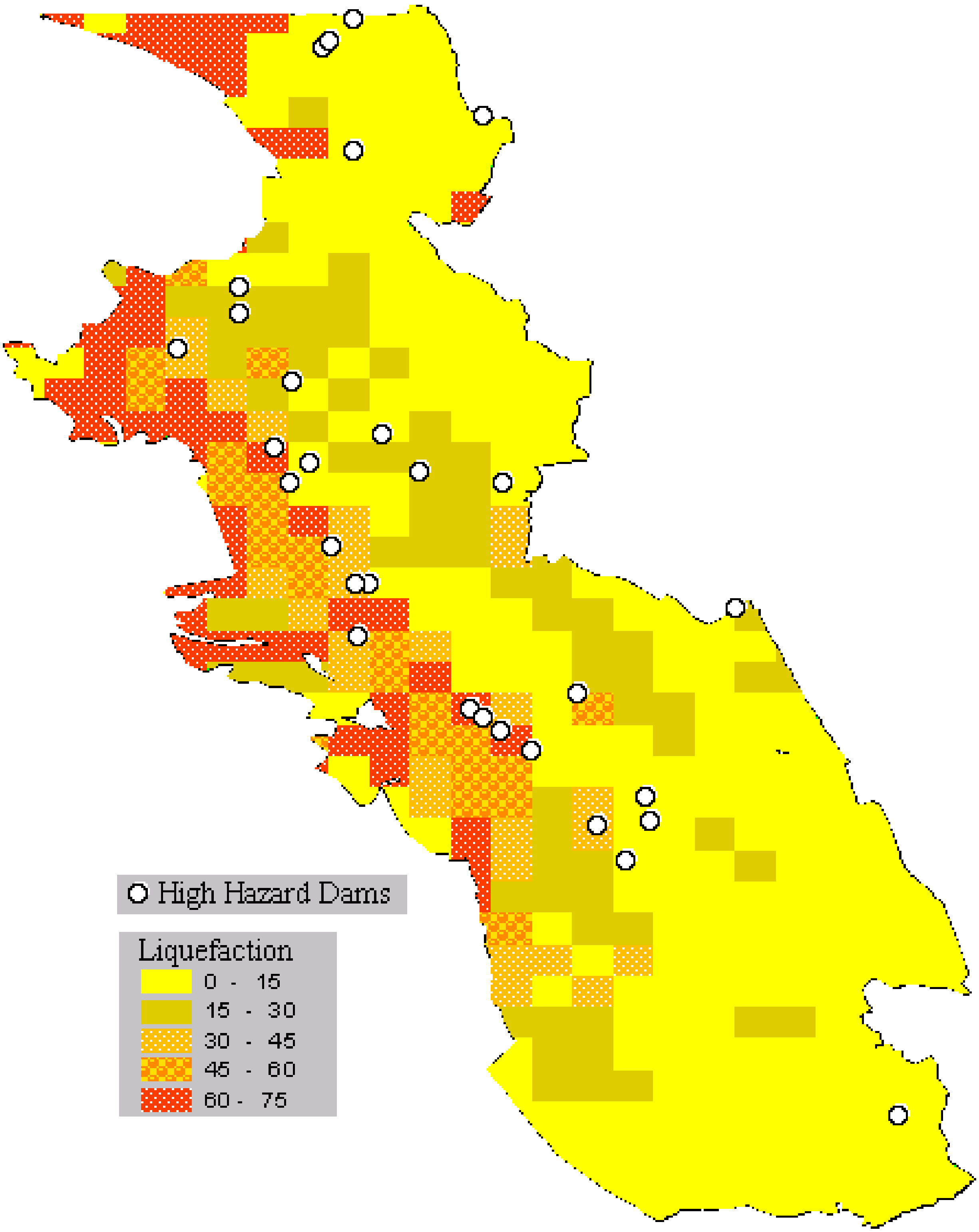
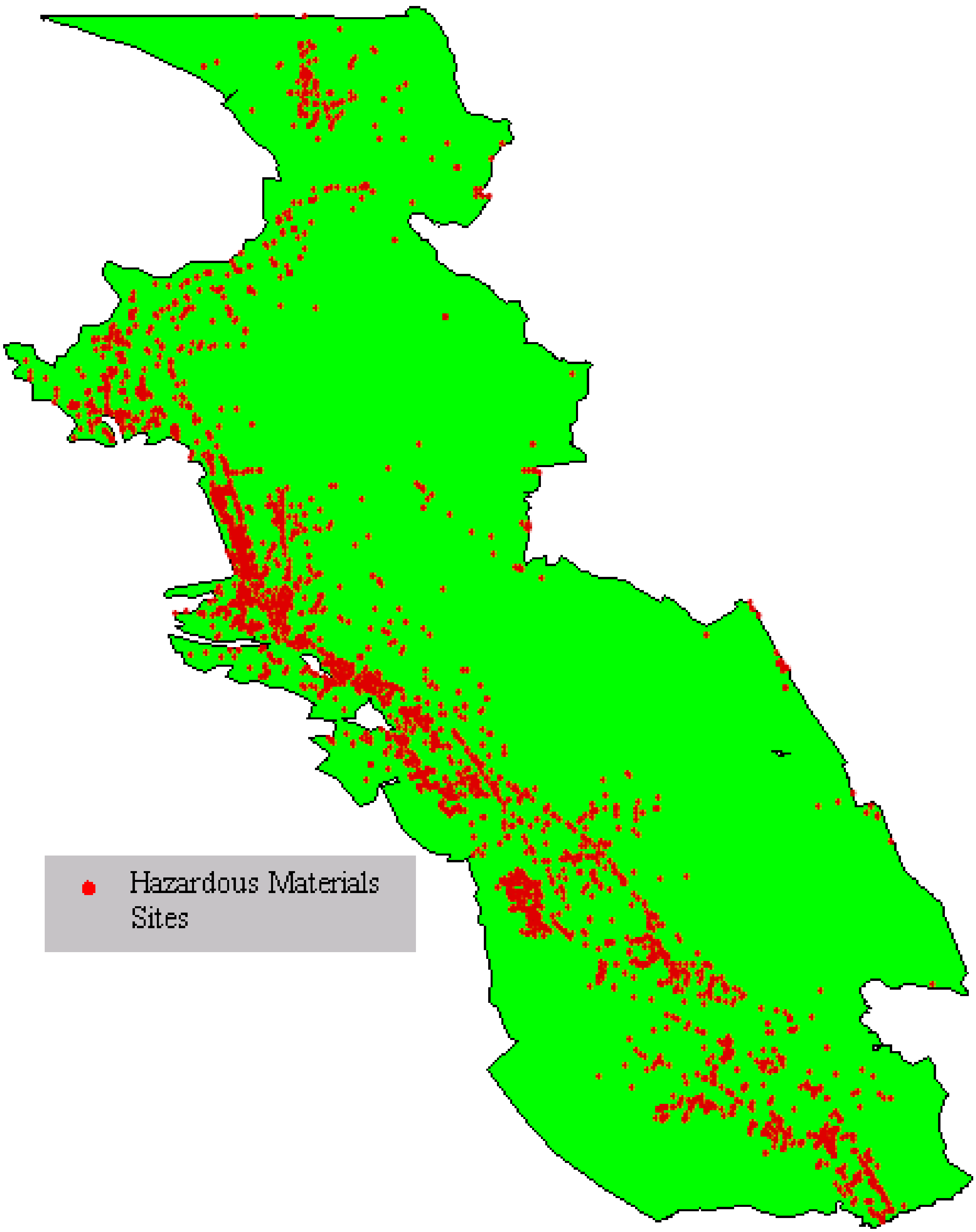


Figure 11 – Sample HAZUS Map: Hazardous Materials Site



Community Mitigation Planning - The 10 Steps to Preparing a Successful Plan

Introduction

A community mitigation plan is an effective tool for "sustained action taken to reduce or eliminate long-term risk to people and their property from hazards and their effects" (FEMA). The plan is a written statement of facts, goals and objectives, a review of available and feasible alternatives, a compilation of recommendations, and a list of final actions to be pursued in the short- and long-term. Essential elements of the plan include assessing a community's hazards, determining its level of exposure to them, and estimating potential losses.

Anyone can prepare a plan, but only by following a proper planning process can one determine what is best for a community and get all those affected to agree on what to do to make the community less vulnerable. Preparing and adopting a community hazard mitigation plan can be implemented in the ten-step process described in this section.

Plans may address a single hazard, flooding being the most common, but increasingly mitigation plans address multiple hazards. Salem, Oregon's plan, for example, addresses floods, landslides, earthquakes, severe wind and ice storms, wildland-urban interface fires, volcanic eruptions and hazardous materials incidents. While tsunamis do not threaten Salem, the plan does recognize the city's potential role as an evacuation center for coastal residents and visitors if tsunami warnings are issued.

The elements of community mitigation planing include:

- Assessing a community's current mitigation activities and their effectiveness;
- Identifying additional mitigation measures that should be undertaken, such as setting aside flood hazard areas as open space;
- Defining strategies and methods to implement mitigation measures, such as using a capital improvement program to realign or replace roads; and,
- Serving as a qualifying document for various hazard mitigation programs, such as those administered by FEMA and the Corps of Engineers.

Successful mitigation planning depends on the committed involvement of people and organizations within an affected community. The process described in this section is a framework for structuring the involvement of affected parties. It also provides a helpful framework for discussing the use of HAZUS' loss estimation results for mitigation planning and, particularly, earthquake risk reduction planning.

Understanding Natural Hazards and Risks

Information about the existence, history, extent, and occurrence of earthquakes is essential to preventing future losses. The key concepts are understanding the words "hazard" and "risk" in this context. Hazard is used generally to describe the nature of the event-causing agent, such as the presence of active faults that generate earthquakes. Risk is used to describe the exposure or vulnerability of human settlements and systems to damage from earthquakes.

The best possible scientific, technical, engineering, social, economic, and demographic information is needed to support effective mitigation planning, programs, and practices. The HAZUS User's Manual (Chapter 1, especially Table 1.1) describes the national datasets included in the software for both ground shaking hazards and key risk components, such as the general building stock, essential facilities, and transportation and utility systems, and it provides instructions for setting up study regions and obtaining damage and loss results for key risk components, as well as identifying selected social and economic impacts. The manual also emphasizes the importance of supplementing HAZUS national data with more current and accurate local data.

Community Mitigation Planning - the Ten Steps

The process is the key. The shaded area on the following page contains an outline of the ten-steps and indicates the steps in the process where using HAZUS can be most helpful. While the principal objective in preparing a plan is formalizing mitigation planning, there are other benefits, too. It is educational as participants learn more about their own and others' concerns, and about the techniques and measures that can improve the disaster-resistance of the community. Additionally, the act of working together to produce the document gives the participants "ownership" of it. A more complete discussion of this process may be found in the first issue of the *Natural Hazards Informer* (see References).

The role of HAZUS in the process will be to serve as a tool for helping to understand the community's hazard and potential losses from scenario earthquakes, evaluating the accuracy of the national datasets, and identifying the sources of better or more current local information.

A Ten-Step Community Hazard Mitigation Planning Process
And how HAZUS can be useful to the process

Step 1 **Organize to Prepare the Plan**

Use HAZUS outputs as a resource for information and graphics when preparing planning documents.

Step 2 **Involve Citizens**

Use HAZUS outputs as exhibits at meetings to provide an illustration of potential hazards and losses.

Step 3 **Coordinate with Other Organizations**

Use HAZUS outputs at meetings to demonstrate the effects of earthquakes on the public and private sectors.

Step 4 **Assess the Hazard**

Use HAZUS to estimate the comparative severity of potential earthquakes and to identify historical earthquake threats.

Step 5 **Assess the Problem**

Use HAZUS products to document potential damages and losses.

Step 6 **Set Goals**

Use HAZUS products to support identification of mitigation goals and objectives.

Step 7 **Review Possible Activities**

Use HAZUS products to support identification of mitigation measures.

Step 8 **Draft an Action Plan**

Use HAZUS analyses to provide supporting documentation for a mitigation plan.

Step 9 **Adopt the Plan**

Use HAZUS outputs to continue to serve as informational, consensus building, and decision support aids.

Step 10 **Implement, Evaluate, and Revise**

Use HAZUS to update inventory data on your community's built environment.
Use HAZUS' updated inventories to produce more reliable loss estimation results.
Use HAZUS' periodic improvements to expand HAZUS' mitigation support roles.

Step 1. Organize to Prepare the Plan

The planning process will succeed only if the right people and agencies are involved at the right times. This requires organizing staff, appointing a planning committee and a lead planner, and holding meetings to discuss objectives and to monitor progress.

The Planner: The person in charge of the planning process is the "Planner." Selecting that person is the crucial first step in the process. The appointed planner must be officially designated as having the authority to develop the plan and is responsible for completing the plan in a reasonable amount of time, ensuring its adoption, and monitoring its implementation. In some communities, a planning department official may fill this role. In others, it may be filled by an emergency manager, council member, or the chair of the citizens' planning committee. While a consultant may provide valuable guidance, the person in charge should be a local official or citizen.

The planner needs an open mind about the variety of possible risk reduction measures that should be considered. Different professionals will bring their own preferences to the process. For example, planning implemented by engineers often favors structural measures; plans prepared by emergency managers may emphasize preparedness activities; and planners may favor regulatory or land-use policies.

Staff Resources: Staff from all affected departments should participate in the planning process. Which staff to involve depends on the community's organization and the mitigation measures that will likely be reviewed and/or selected during the planning process. Staff who likely will be responsible for helping to implement the plan should be involved in the planning process, as they need to understand what is expected of them and be willing to work toward the plan's implementation. Also, the planner will need technical support from engineers and other staff professionals who are more familiar with some of the appropriate mitigation measures. Involving participants from various disciplines, professions, and interest groups will make the plan more comprehensive.

HAZUS supports this process by focusing attention on losses to identify potential mitigation strategies and to study possible risk reduction measures. An earlier section of this *Guide* describes several of the most common mitigation strategies available to communities.

Planning Committee: It is recommended that a Planning Committee of 10 to 15 people comprised of local officials, community staff and private citizens conduct the planning process. This structure has proven to be very helpful in providing information on the needs and concerns of the groups, and in keeping the community up-to-date on how the plan is progressing. An individual should be appointed to head the planning committee as the Chairman. The head of the planning committee should be chosen for his or her ability to get people to work together and get things done. The planner or other staff member provides administrative support, such as taking minutes and sending out meeting notices.

The committee will likely need subcommittees who can spend more time on details that do not need to be discussed during the meetings of the main committee. Usually the Chairman is given the authority to name subcommittees and appoint their members.

A planning committee can:

- Be an effective forum for matching the technical requirements of a program to the community's needs,
- Give the participants a feeling of "ownership" of the plan and its recommendations, which helps build public support for it, and
- Form a constituency that will have a stake in ensuring that the plan is implemented.

Using HAZUS' results as a point of departure, community staff members can support the mitigation planning process. For example, the planning and community development representatives can explain the community's historic evolution, current configuration, future development patterns, and current growth management policies and interpret these in light of potential hazards issues. The building official can supply information about the earth-

Staff and Expertise to be Included in the Mitigation Plan

- Land-Use Planner: existing land uses, demographics, building occupancies, infrastructure, planning direction and coordination with other plans and programs
- Geotechnical Engineer: local geological and soil conditions
- Structural/Civil Engineer: hazardous sites, building and lifeline vulnerabilities, codes and structural mitigation measures
- Utility and Public Works Representative: streets, highways, bridges, utilities, mitigation measures and maintenance
- GIS Specialist: databases, maps, map analyses, data input into HAZUS
- Emergency Manager: emergency services planning, response and recovery needs
- Police and Fire Officials: emergency services
- Building Code Official: building codes and zoning ordinances
- Fire Marshal: hazardous design practices, materials, buildings and sites
- Parks Official: open space, parks and forest preserves
- Public Relations: community relations and public information on property protection measures and public involvement
- Governing Board or City Manager's Representative: political acceptance and adoption of mitigation plans

quake design requirements of earlier and current building codes, often very useful in establishing "benchmark" years when at least some earthquake resistant design requirements were initiated. The identification of areas with poor soils could help staff from the parks and recreation department define areas that should remain as open space or recreational areas.

Meetings: At the first Planning Committee meeting, a schedule should be established. Depending on deadlines, time constraints, and staff time available, committee meetings could be held as often as once or twice a month. Scheduling meetings in advance should be done so as many people are included as often as possible.

HAZUS' outputs, such as maps and tables, can serve as effective exhibits at committee meetings, and can provide a continuing source of shared information that is enriched throughout the process so increasingly accurate information is used, confidence is built, and the crafting of effective, practical, and acceptable mitigation measures can occur.

Determining who has a vote usually is not necessary, as issues are usually decided by consensus.

One key threat to the planning process is that it starts to drag and become a bore. Nine months of monthly meetings with nothing to show but a draft piece of paper can discourage many committee members. It is important to maintain momentum throughout the process.

Field trips are very educational and allow committee members to see the problems and examples of solutions first hand. Such field trips often change the minds of those skeptical about some of the potential measures. They also can serve to break up the monotony.

The Planning Committee's work is not done when the governing board adopts the plan. The Planner should give the committee assignments, such as developing some recommendations in more detail, helping with the design and implementation of some projects, and monitoring the community's progress in implementing the action plan.

Consensus: *Ideally, various groups should seek consensus on procedures, goals, and issues.* Consensus *means a general agreement or something everyone can live with.* Consensus *does not mean majority vote.*

Step 2. Involve Citizens

The involvement of citizens is critical to the success of mitigation planning. Citizens have their own missions, obligations, and concerns and hazard mitigation may not be one of their highest priorities. Citizens can help in designing effective programs by providing support for them.

Citizens include:

- Owners and renters of vulnerable houses and commercial buildings,
- Representatives of homeowner, business, or neighborhood organizations,
- Managers of critical facilities, such as large businesses, power stations, and schools,
- Land developers, real estate agents, lenders, and others who affect the future of the community's land use and building standards, and
- Representatives of special purpose districts, councils, or associations such as fire protection districts, water districts, and councils of government.

Citizens may become involved in a variety of ways including:

- Serving on the Planning Committee,
- Attending meetings that address the issues that are most important to them,
- Providing input to the process through questionnaires or by hosting a workshop to gather input and give guidance to the Planning Committee,
- Conducting an "Earthquake Preparedness Week" or a demonstration project to attract public attention and raise the community's level of awareness and interest in earthquake risks, and
- Providing review of the draft plan.

The level of citizen involvement depends on how much time they have available and how strongly the issues affect them. One of the most important things is that they are asked to participate and that they are offered a chance to have a say in your planning work. A good leader will make sure everyone is heard. You need them to make sure that committee proposals will be acceptable to their constituencies.

Step 3. Coordinate with Other Organizations

There are two reasons to involve other organizations in the planning process. First, others may be implementing, or planning to implement, activities that may affect your community's exposure to earthquake risk. You need to make sure that your efforts are not going to be in conflict with a government program or duplicate the efforts of another organization. State, regional and federal agencies may be undertaking various mitigation efforts or projects. While such planning initiatives may not address all local issues, they likely will thoroughly evaluate mitigation alternatives applicable to their programs, which can save you a lot of work.

Secondly, outside agencies and organizations may offer help in the form of hazard data, technical information on various risk reduction measures, guidance on regulatory requirements, advice and assistance in the planning process, implementation of a recommended measure, and financial assistance.

Step 4. Assess the Hazard

Earthquake hazards and the related risks to the community need to be assessed before decisions can be made about their implications, relative importance and the scope of a plan's recommendations and the structure of its specific actions. The Planning Committee should identify the nature, frequency, and characteristics of all significant earthquake hazards and risks over an often-lengthy period of time (100-200 years is not unusual). Historical information is very important, as are research and technical studies that provide information about severity, probabilities of occurrence, and other factors.

HAZUS, as noted earlier, will help to identify the comparative severity of potential earthquakes. Major to great earthquakes may rarely occur, but they are capable of causing enormous regional losses and impacts. Small to moderate earthquakes occur relatively frequently and can result in limited but possibly locally severe damage. But potential losses from frequent relatively minor events add up to great losses over time. This analysis helps determine the appropriateness and priority given to mitigation efforts. It may be judged prudent and cost-effective to strengthen existing earthquake hazardous buildings so life safety risk and economic and service interruption are greatly reduced for the more frequent moderate events, but these same buildings could be allowed to suffer extensive damage in very rare great events. On the other hand, the same community's fire stations may be strengthened to a higher performance level because, as critical facilities, their response capabilities cannot be impaired.

Step 5. Assess the Problem

Getting everyone to agree on a problem statement is the first step in getting them to agree on goals and solutions to solve the problem. Developing a problem description, including data and maps, such as those that can be provided by HAZUS, is an essential first step in assessing the problem. How much time and effort is spent on collecting data depends on the time and resources available. However, the planning process should not be delayed while waiting for more data in order to develop a detailed problem description.

Since earthquakes impact more than just buildings, HAZUS and other information should be used to assess potential effects on the following:

- Road, bridges, and transportation facilities likely to be closed
- Critical facilities affected (e.g., hospitals damaged or isolated)
- Areas of potentially extensive damage (e.g., those with weak soils)
- Vulnerable utility systems (e.g., water, electricity, natural gas)
- Damage from past earthquakes in the community or other communities
- Undeveloped areas as well as areas slated for planned development
- Special or historic structures or areas

A final topic that should be addressed is the future. Your problem definition should review expected changes to the community (e.g., existing Master Plans), including the development potential of vacant land and plans for the redevelopment of existing areas.

Step 6. Set Goals

Up to now, the planning work has been relatively non-controversial. The process has mostly involved talking to agencies and organizations and collecting and recording facts. Now comes the tough part: getting people to agree on what should be done by setting goals.

Those involved in the planning process will need to prepare a clear statement of goals and objectives to identify and clarify concerns and develop the means for addressing them. Goals are general statements of direction, such as “reduce potential earthquake damage to existing buildings” or “improve building codes for new construction.” Objectives are more specific targets. Examples of objectives that support these two goals could be “require that all unreinforced masonry buildings between Main Street and 1st and 3rd Streets be structurally upgraded to meet the seismic requirements of the most recent version of the International Building Code” and “ensure the adoption of the latest building code and its effective enforcement by qualified and trained people from our Department of Building Inspection."

Reaching Agreement: It is often easy to reach agreement on overall goals, but it is not unusual to take a long time to reach consensus on specific objectives. The time spent on reaching consensus on objectives is well spent because it is vital to gaining agreement and cooperation from all affected parties. The Planner should strive for unanimous support so that no one will oppose a goal or objective. If unanimous agreement is not possible, a decision by majority vote is common although voting is always potentially divisive.

It helps if goals are positive statements, something people can work for, not negative statements about the community. Where possible, settle on goals and objectives that support more than one interest (e.g., implement seismic rehabilitation measures for existing buildings in areas to be redeveloped and made more economically viable to the community).

The following approach may be used to reach agreement:

- Have all participants write down their goals and objectives,
- Post them for all to see, combining those that are the same or similar,
- Restate them in summary form, using positive statements,
- Identify those that all agree on,
- Discuss the problems with the remaining goals and objectives, and
- Determine if agreement can be reached with some changes.

If this approach fails to work, there are two options. Either drop the more detailed statements and get consensus on the general goals or invite an experienced facilitator to help the group move through a formal process of consensus-building. A facilitator can be very helpful as a neutral outsider to give all interests a chance to be heard. Facilitators also know numerous exercises and other ways to identify common concerns and minimize differences. They are skilled in separating issues and interests from discussions of people and positions and can build an environment where give and take is easier and productive. A facilitator should be lined up in advance so momentum is not lost in arguing over details.

Step 7. Review Possible Activities

Different mitigation measures can be used to meet the objectives. Many of them are inexpensive and easy to implement, while others are more complex and costly. Successful planning requires careful examination of all possibilities.

The many mitigation measures likely to be suggested can be used as a checklist to ensure that everything has been considered. While some of the measures may be quickly eliminated as inappropriate, most deserve careful consideration, especially to ensure full understanding of how they work, their impacts on the community's current and future configuration, and their general benefits and costs. The potential measures should be systematically reviewed, discarding only those that do not meet the following criteria:

- Technically appropriate for reducing earthquake risk,
- Support the goals and objectives,
- Benefits equal or exceed costs,
- Affordable and has a funding source,
- Complies with all local, state, and federal regulations,
- Politically acceptable, and
- Administratively feasible.

In some cases, answers will not be readily available. Questions about technical aspects or agency programs should be directed to experts or representatives from agencies or organizations.

Money is often the most important issue in reviewing alternatives. Three questions arise: "Is the action worth the expense?" "Who pays and who benefits and when?" and "Where can we get the money?" The answers will greatly determine the final structuring of the proposed mitigation action and its acceptability to community interests.

This is also where the agencies and organizations that have been involved in the process can be of great assistance. There are literally hundreds of public and private funding programs, but they usually have several prerequisites, such as a written plan, a budget and an explanation of the benefits. For example, one project might be funded by several different parties, each of which is serving one or more objectives. Often, the agencies can fund only a part of the project, and they favor those projects that have other sources of funding. In other words, they want their money to go farthest, so they will support multi-objective projects. Often, "in-kind" (non-cash) services can be counted toward the local share needed to match an outside source of funds.

Local businesses and other organizations will frequently support projects that benefit their customers, employees, or members, or that make for good advertising. Many projects have direct financial benefits as well. For example, a shared resources program to seismically strengthen dwellings owned by employees of major local employers achieves multiple benefits: reduced employee losses and the costs of dislocation, employees' more rapid return to work resulting in lower business interruption losses for the employer, and fewer insurance claims and applications for disaster assistance.

Step 8. Draft an Action Plan

Only after assessing the problem, setting goals and objectives, and reviewing all the possible solutions, can the most appropriate actions be recommended in the written plan. The plan should contain the recommendations detailing what will be done, by whom, and when.

The plan can be in any format but should include three sections:

1. A description of how the plan was prepared: This helps readers (and potential funding agencies) understand the background and rationale for the plan and how public input was obtained. HAZUS can be used to help produce supporting documentation for aspects of the plan addressing hazard assessment and potential damage and losses.

2. Recommended actions: The plan should clearly identify who will do what, over what time frame and whether existing resources are adequate or new ones needed. Special attention should be given to actions that need to be taken by others, such as a state's legislature.

3. A budget: The plan should explain how its recommendations will be financed. It should note those recommendations that can be implemented as part of a community or organization's normal operations without special funding.

Step 9. Adopt the Plan

The community should make the draft plan available for review by affected businesses, appropriate community government departments, interested organizations, state and federal agencies, and neighboring communities. After allowing several weeks of review time to digest the plan, a public meeting or workshop should be held. A public meeting is a requirement for many funding programs. As with many activities during this process, HAZUS' outputs continue to serve important informational, consensus-building, and decision-support roles.

A public meeting is not the same as a public hearing. State or local laws usually require a public hearing when a community is considering adopting or amending a land use plan or zoning ordinance. There are specific legal requirements for notifying the public and conducting such a hearing. These legal requirements need not be met for mitigation plans in most communities.

In preparing for a public meeting, adequate notice of the date, time and place should be given, and information about the plan should be distributed well in advance. The notice should tell people where to obtain a copy of the draft plan for review before the meeting.

After the meeting, the community's mitigation Planning Committee should make appropriate changes to the plan. The governing board should adopt the final plan. It is always helpful to gain support from other entities. If Planning Committee members were selected to represent a particular interest or organization, those organizations should pass a resolution or otherwise officially support the plan.

Step 10. Implement, Evaluate, and Revise

Adoption of the earthquake hazard mitigation plan by the various participants is not the last step. Monitoring and follow-up will be needed to ensure that the plan is implemented. The plan can be periodically improved by adding new building inventory data and local geologic data to increase the reliability of damage and loss estimates. This will allow more effective decisions to be made about allocating mitigation resources.

HAZUS is also revised and reissued periodically and can continue to serve loss reduction by portraying changes in the community, especially its physical development; noting the implementation of mitigation measures, such as zoning restrictions in poor soils areas; and improving disaster response capabilities, such as by labeling those fire stations that have been seismically rehabilitated. In addition, new improvements to HAZUS' methodologies and software can be used to improve and update the mitigation plan's supporting documentation.

Implementation: The key to successful implementation is that all the involved parties responsible for the various recommendations understand what is expected of them and are willing to work toward implementation. It is helpful for the plan to identify the implementing agency or organization and a designated person to be responsible for implementing each recommendation.

The plan should identify visible and generally acceptable actions that can be quickly implemented, such as evaluating the expected earthquake performance of the jurisdiction's fire stations or adopting the latest building code seismic provisions governing new construction. Immediate progress helps encourage citizens and the Planning Committee participants. Caution should be exercised when actions are retroactive in nature, such as requiring owners of existing buildings to improve them within a short time. Such proposals often founder on the rocks of political unacceptability.

Monitoring: No plan is perfect. As implementation proceeds, changes will be needed. The plan should have a formal process to measure progress and to develop recommended changes. A monitoring system helps ensure that all parties act on their assignments in a timely manner. This can be in the form of a checklist maintained by the person designated as responsible for the plan or by using a more formal reporting system to a higher authority, such as the governing board or an oversight committee.

Evaluating and Seizing Opportunities: Even with full implementation, the plan should be evaluated periodically to determine progress and to evaluate changed conditions. The Planning Committee should meet to review progress and submit its recommendations to the agencies and organizations responsible for implementation.

While a plan will usually produce the best and most efficient program, a community should be ready to act fast to take advantage of opportunities provided by the necessity of dealing with disasters, extra end-of-the-year money, changes in other public concerns, or heightened public interest due to disasters elsewhere. There may be a chance to effect major changes quickly. Research and experience have clearly shown that "windows of opportunity" open, sometimes only for very short periods.

A Closing Reminder

Earthquake loss reduction is a complex long-term commitment. It requires the continuing participation of a team of people from virtually all of the city's departments, regional providers of key services (such as utility companies and special districts), and others whose holdings and services affect the city. The importance of a strong mitigation planning team is discussed in *Community Mitigation Planning - The 10 Steps to Preparing a Successful Plan*. While it may be difficult to assemble and sustain such a team in many localities, such a structure is absolutely essential to designing and implementing effective hazard mitigation programs.

Mitigation requires trade-offs for practical economic, social, and political reasons. A community might require strengthening for its few conventional masonry buildings because local opposition is small. A neighboring community with a large number of such buildings might prefer improved codes for new construction and avoid retroactive requirements. This course might be seen as politically safer, less costly, and not as socially disruptive.

Preventing earthquake losses through effective hazard mitigation programs and plans implemented in advance and over the long-term is the key to protecting people, buildings, and systems and to saving money. This *Guide* is a small addition to other materials available to users to help them understand their earthquake vulnerability and to take effective measures to limit their exposure. The benefits from effective mitigation are many: lives saved, injuries avoided, utility services operational, businesses open, transportation and communications systems working, and potentially enormous response and recovery costs avoided.

If you have successfully used HAZUS in an earthquake mitigation program, providing others with the benefit of your experience is in itself a powerful mitigation tool. We ask you to contact the Federal Emergency Management Agency, Mitigation Directorate or the National Institute of Building Sciences, Multihazard Loss Estimation Program to add your experience to the growing list of HAZUS success stories.

Important Message to HAZUS Users

HAZUS is designed to produce loss estimates for use by federal, state, regional and local governments in planning for earthquake risk mitigation, emergency preparedness, response and recovery. The methodology deals with nearly all aspects of the built environment, and a wide range of different types of losses. Extensive national databases are embedded within HAZUS, containing information such as demographic aspects of the population in a study region, square footage for different occupancies of buildings, and numbers and locations of bridges. Default databases and parameters have been included as needed. Using this default information, users can carry out general loss estimates for a region. The HAZUS methodology and software are flexible enough so that locally developed inventories and other data that more accurately reflect the local environment can be substituted, resulting in increased accuracy.

Uncertainties are inherent in any loss estimation methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effects upon buildings and facilities. They also result from the approximations and simplifications that are necessary for comprehensive analyses. Incomplete or inaccurate inventories of the built environment, demographics and economic parameters add to the uncertainty. These factors can result in a range of uncertainty in loss estimates produced by HAZUS, possibly at best *a factor of two or more.*

The methodology has been tested against the judgment of experts and, to the extent possible, against records from several past earthquakes. However, limited and incomplete data about actual earthquake damage precludes complete calibration of the methodology. Nevertheless, when used with default inventories and parameters, HAZUS has provided a credible estimate of such aggregated losses as the total cost of damage and numbers of casualties. HAZUS has done less well in estimating more detailed results - such as the number of buildings or bridges experiencing different degrees of damage. Such results depend heavily upon accurate inventories. HAZUS assumes the same default soil condition for all locations, and this has proved satisfactory for estimating regional losses. Of course, the geographic distribution of damage may be influenced markedly by local soil conditions. In the few instances where HAZUS has been partially tested using actual inventories of structures plus correct soils maps, it has performed reasonably well.

Users should be aware of the following specific limitations:

- While HAZUS can be used to estimate losses for an individual building, the results must be considered as average for a group of similar buildings. It is frequently noted that nominally similar buildings have experienced vastly different damage and losses during an earthquake.
- When using default inventories, accuracy of losses associated with lifelines may be less than for losses from the general building stock. The default databases and assumptions used to characterize the lifeline systems in a study region are necessarily incomplete and oversimplified.
- Based on several initial studies, the losses from small magnitude earthquakes (less than M6.0) centered within an extensive urban region appear to be overestimated.
- Because of approximations in modeling of faults in California, there may be discrepancies in motions predicted within small areas immediately adjacent to faults.
- There is considerable uncertainty related to the characteristics of ground motion in the Eastern U.S. The default attenuation relations in HAZUS, which are commonly those recommended for design, tend to be conservative. Hence, use of these relations may lead to overestimation of losses in this region, both for scenario events and when using probabilistic ground motions.
- As yet, there have not been adequate tests for the following features of HAZUS:
  - Effects of liquefaction and landsliding
  - Debris generation
  - Indirect economic losses

HAZUS should still be regarded as a work in progress. Additional damage and loss data from actual earthquakes and further experience in using the software will contribute to improvements in future releases. To assist us in further improving HAZUS, users are invited to submit comments on methodological and software issues to Philip Schneider at pschneider@nibs.org.

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Acknowledgments

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